

Sea Energy Conversion: Problems and Possibilities

G. Buigues¹, I. Zamora², A. J. Mazón, V. Valverde and F.J. Pérez

Electrical Engineering Department
E.T.S.I.I., University of Basque Country
Alda. Urquijo s/n, 48013 Bilbao (Spain)
Tel.:+34 946014063, Fax:+34 946014200
e-mail: ¹ garikoitz.buigues@ehu.es, ² inmaculada.zamora@ehu.es

Abstract.

Nowadays, policies are being developed in many countries in order to decrease their greenhouse gases emissions. While in this area some technologies are widely installed (wind and solar energy), other ones, like the sea energy, could get an important role in the medium and long term. That is why the most relevant technologies associated to the sea energy conversion are presented in this paper: Tidal energy (both the traditional power plants and those based on tidal streams), wave energy and ocean thermal energy conversion.

However, the sea energy conversion is not completely developed yet due to some unsolved technical problems, apart from their high cost. The most important advantages and disadvantages related to each kind of technology are also analyzed in this paper, comparing the main characteristics among them.

Therefore, technological development government policies and the possibility of setting up a related industrial field will be the key actions to make possible the future of the sea energy. Solving the economical and technical problems, it will be possible to make good use of this alternative source of energy, with high energy density.

Keywords

Sea Energy, Tidal Energy, Wave Energy, Ocean Thermal Energy Conversion.

1. Introduction

The available sea energy is enormous. If only a 10% were used to generate electricity, it would be a significant amount of energy regarding to the total world energy. In fact, the possible sea energy sources and consequently the conversion systems are divided in three main groups:

- Tidal Energy: Making use of the potential energy of the different sea levels created by the tidal effect or by using directly the energy of the tidal streams
- Wave Energy: It is mainly caused by the wind effect on the sea.
- Ocean Thermal Energy: This energy is harnessed by using a thermodynamic cycle between the different temperatures of the ocean deep and surface water.

During the last decades, several devices and equipments have been developed to convert the sea energy. But only

a few ones have become real-scale prototypes to be tested on the sea. Nevertheless, an exception is La Rance (France) tidal power plant, which has been generating energy over the last 40 years. Apart from the tidal energy, the other kinds of sea energies are also being tested obtaining different results, some of them closed to the theoretical calculations and other ones quite different. That is why the real condition trials are essential to evaluate their possibilities, neither tank testing nor computer simulation can replace them.

Besides their technical problems, economical ones should be taken into account. Nowadays, the cost of the produced sea energy can not compete with other renewable energies or with the traditional ones. Furthermore, it is usually difficult to obtain the project funding, due to the destruction risk associated to weather conditions.

In this paper, the most important technologies associated to the sea energy conversion are analyzed, specifically the following ones:

- Tidal energy (conventional power plants and those that harness the energy of tidal streams)
- Wave Energy (shoreline and offshore technologies)
- Ocean Thermal Energy Conversion systems

2. Tidal Energy

The tidal energy is the energy stored by the ocean due to the tides produced by the combination of different effects:

- The gravitational effect of the Sun and the Moon
- The Earth's rotation
- Other factors, such as different ocean depths at different places, odd shapes of the continents, Earth tilt, etc.

Depending on the location, it is also possible to find a once-a-day tide (one high-tide and one low-tide a day), twice-a-day tide (two high-tides and two low-tides a day), and so on. Therefore, tides can be considered as the longest sea waves, with high periods (12-24 hours) and wavelengths comparable to the length of the Earth's equator circumference.

Considering the different ways of using this type of energy, the technologies are classified in the following way:

A. Traditional Tidal Power Plants

Many centuries ago, the tidal energy was firstly used storing water in the high tide for a later use of its potential energy to move till wheels. Although the first equipments on the 20th century also used this system, the potential energy has a different application. The water stored during the high tide by a river estuary dam is released to move a bulb turbine, generating electricity (i.e. La Rance Power Plant in France, figure 1). These systems can be considered as the first generation ones.

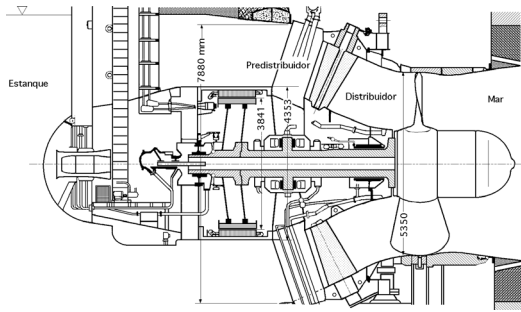


Fig. 1. Bulb Turbine (La Rance Tidal Power Plant) [1]

Reversible turbines are usually installed in this kind of power plants, making use of the streams of both tides (high and low). It is also important to consider the importance of the difference between high and low-tide sea levels. The higher the difference is, the higher the energy produced will be. Nowadays, five meters is considered the minimum difference needed to produce commercial electricity.

The theoretical energy available in a tide cycle depends on the reservoir area and on the square of the maximum tide amplitude, which fixes the reservoir maximum height.

Considering the previously mentioned level difference required to produce energy, there is only a few places in the world with enough tide amplitude. Table 1 shows an example of some of them.

Country	Place	Tide average height (m)	Estimated Power (MW)	Estimated generation GWh/year
Argentina	Rio Gallegos	7,5	1900	
Australia	Walcott Inlet	7	2800	
Canada	Cobequid	12,4	5338	14000
Russia	Penzhinsk	11,4	87400	190000
USA	Turnagain Arm	7,5	6500	16600
India	Khambat Gulf	6,8	7000	15000
UK	Severn	7	8640	17000
Korea	Garolim	4,7	400	

Table 1. Suitable places to install tidal power plants [1]

An important disadvantage of this kind of energy is the high cost of the installed power (1500 €/kW). Apart from that, the long construction time (5-15 years) and a low

load factor (22-35%) due to the variable tide amplitude. The environmental impact produced by the changes of hydrodynamic regime has also to be considered.

Another negative factor is the long distance between the power plants and the load demand, requiring long transmission lines.

The main advantages are the low operation and maintenance cost (< 0.5%) and its high availability (> 95%), with a high number of generator-turbine groups. Some examples of this kind of installations are:

- Kislaya Power Plant (Kislogubskaya), located on the White Sea in Russia. It uses a 0.4 MW bulb turbine, and started working as a pilot plant in 1968. It is the second in the world of its kind.
- Power plant located on the east coast of Canada, at the estuary of the Annapolis River on the Bay of Fundy. By an 18 MW Straflo turbine, it started working in 1984 [1].

All the mentioned negatives points influence many countries not to invest in this kind of power plants. However, R&D related to the tidal streams based power plants explained below have higher promotion due to its advantages and future perspectives.

B. Tidal Streams Power Plants

Today's tendency towards tidal energy production is the use of equipments to convert the tidal streams energy, also called second generation systems. These systems do not need large dams to collect the water in the reservoir. Although in some places it is not possible to make use of the existing tides, the tidal streams are usable to produce energy. To this purpose, different kinds of turbines have been developed for a submerged installation in suitable locations.

The world available tidal stream energy is estimated at 5 TW (Isaacs and Seymour 1973), approximately the world energy demand. Nevertheless, in spite of the uncertainty about the existing resources, only a little part of that energy could be used because of the streams locations. They can usually be found near the oceans periphery or through straits between islands or other geological shapes. Besides, from the economical point of view, only 1 m/s or above streams are usable for energy generation purposes.

The most important positive factors to take into consideration are the high predictability of the sea streams and the high load factor of these installations (20-60%).

The available power in tidal streams can approximately be obtained from the following expression:

$$P_{tma} = \frac{1}{2} \cdot \rho \cdot V_{rnc}^3 \cdot A$$

Where:

- P_{tma} = Total mean annualised power (W).
- V_{rnc} = Cubed root of the mean of the cubes speeds (m/s).
- ρ = Current water density (kg/m³)
- A = Cross-sectional area (m²)

Since extracting all the available stream power could be environmentally damaging, it is necessary to use a factor that expresses the usable power percentage with apparently no damaging consequences. It is called SIF (Significant Impact Factor) and Black and Veatch (a British consultant company) considers it should be 20% [2].

$$P_{Asite} = \frac{1}{2} \cdot \rho \cdot V_{rnc}^3 \cdot A \cdot SIF$$

Four are the proposed tidal stream energy conversion systems considered nowadays:

1) Horizontal-axis turbines

They look similar to wind turbines, and can be installed either seabed-mounted or hanging from floating platforms. The extractable energy depends on the rotor diameter and current speed (figure 2)

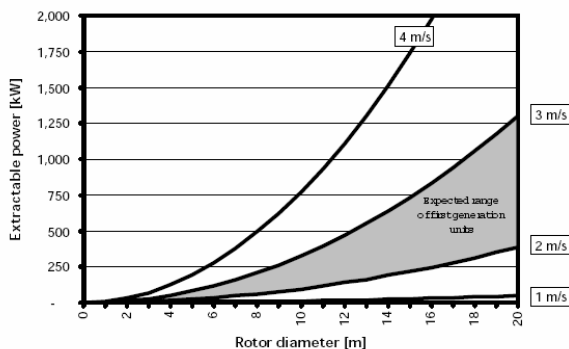


Fig. 2. Extractable power with a 30% average performance (CEC, 1996) [3]

They may have pitch-controlled blades depending on the stream flow. 10-15 m diameter and 200-700 kW rated power turbines, are probably the most economic overall solution for first generation devices [3].

Some installations that use this kind of technology are:

- Seaflo, with a rated power of 300 kW and 11 m rotor diameter, installed in Lynmouth, Devon (UK) in 2003 [21].
- Hammerfest Strom A.S., Norway, with 300 kW and 20 m rotor diameter, installed in 2003 [10].

2) Vertical-axis turbines

In these turbines, the stream flow is perpendicular to the rotational axis and they are also similar to their wind homologues (Darrius). However, in Darrius turbines the rectilinear blade design produced efficiency but instability at the same time, with high tendency to rupture due to vibrations. After some laboratory tests, it was concluded that using helicoid blades (Gorlov turbine) the vibrations problem is solved and therefore the rupture risk problem.

Another important advantage of Gorlov turbine is the amount of energy extracted from the tidal stream (35%), compared with rectilinear blade Darrius turbine (23%)

and with the conventional horizontal axis-turbine (20%). Besides, the Gorlov turbine always turns in the same direction, regardless what the stream direction is, with higher versatility in energy conversion [4].

An example of this technology is the Enermar Project, which uses a 3-bladed Kobold turbine with a rated power of 130 kW (23% of global efficiency). It is located in the strait of Messina, Italy [10].

3) Oscillating hydroplane device

It is based on a seabed mounted device, called Stingray. The main characteristic of this technology is its large wing-like hydroplane, which can be pitch-controlled, oscillating up and down and compressing oil of an hydraulic power converter. Several prototypes have been tested in several stages with 150 kW and 180 Ton [5]

4) Venturi effect tidal device

It is based on the Rochester Venturi device, developed by Hydro Venturi and installed in the north of England. This system consists of an open venturi tube, which uses the venturi effect to accelerate the water flow. While the water is accelerated, a pressure reduction is generated in the most constricted point, under atmospheric pressure. Subsequently, the pressure gradient force (from high to low pressure) is used to move a conventional turbine inside the tube which is connected with the constricted point [6].

C. Advantages

The most important advantages and disadvantages of tidal energy conversion compared with the other kinds of sea energies are the ones listed below. Some of them are common to both conventional tidal and tidal stream power plants, but other ones only refer to one technology.

1) Advantages

- Highly precisely predictable local energy resources, superior to other renewable energies, such as solar or wave energy.

Conventional tidal power plants

- The bulb turbine technology used in conventional tidal power plants is far developed with reliability and good performance, obtaining low operation and maintenance costs.
- The high availability of conventional power plants is a positive factor to take into account.
- Extensive experience due to the power plant installed in La Rance (France), which has been working during decades.
- Possible transportation improvement due to its application to the development of traffic or rail bridges across estuaries.

Tidal stream power plants

- High sea streams energy density. Compared with the most known wind turbines, seawater is 832 times denser than the air. So the power available in a sea current of 14.81 km/h speed is equivalent to a 390 km/h wind one.
- Vertical axis turbines used in tidal streams conversion can be linked to each other in a grid to make better use of the streams energy in deepest areas.

2) Disadvantages

- There are only a few places where this energy can be commercially used and many times they are quite far away from the energy demand, so the transmission infrastructure could have too high costs.

Conventional tidal power plants

- The conventional tidal power plants are far expensive, with very long construction periods, apart from their reduced load factor.
- Nowadays, the environmental impact of conventional tidal power plants is rather high to be assumed.

Tidal stream power plants

- There is an uncertainty about the existing world energy resources related to tidal streams.
- The turbines used for tidal stream energy conversion must be installed offshore and underwater. Consequently, high operation and maintenance costs can not be avoided.
- During its normal operation, the horizontal-axis turbines withstand high working stresses (higher under bad weather conditions). Besides, there is high probability for cavitation to appear at the blade tips, due to the pressure reduction with its increase in water relative speed.
- The offshore turbines increase the ship crash risk when they are installed near the maritime routes.
- Damaging effects, for both migratory sea species and seabed, due to existing underwater cables and anchorages.
- Today's offshore turbines cost is far higher than the other renewable energies.
- There have been not enough tests to get to know the resistance of these technologies in a sea environment.
- In case of an extended use of this energy conversion, it must be a maximum limit for the extracted energy. Otherwise, the environmental impact could be too high.
- Possible sea spills (lubricant oils, etc.)

3. Wave energy

The ocean waves are mainly produced by the effect of the wind (due to the sun energy) blowing over the surface of the oceans. Considering a solar irradiance of 375 kW/m² over the world surface, only 1 kW/m² is transmitted to

produce waves, which work like an energy storage. Then, these waves move quite easily from one place to another through the oceans, with a speed proportional to their wavelength.

There is no perfect regularity in waves. Their amplitude, energy and direction vary randomly through the year. While sometimes they can change from an absolute calm (1%) to 1 MW/km, in other places they can reach 10 MW/km for a short period of time (minutes). Instantaneous variations are also possible.

The power in a real wave depends on several factors (wave direction, sea depth, etc.), but it is mainly proportional to the square of the amplitude and to the period of its motion. A long period wave (7-10 s) with high amplitude (2 m) could have more than 40-50 kW/m.

As in most renewable energies, the wave energy is not equally distributed over the world. Between the 30° and 60° latitudes of both hemispheres is located the highest energy density, due to the characteristic west winds of these areas. The world wave power distribution is shown in figure 3.

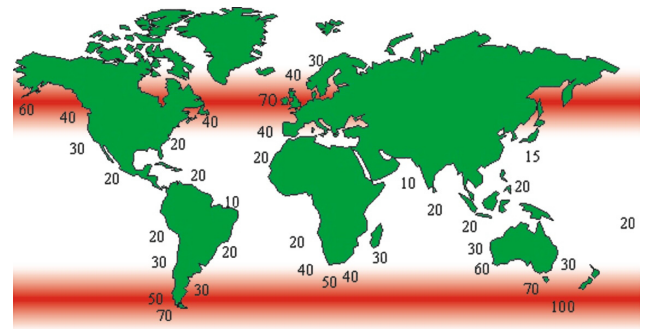


Fig. 3. World wave power distribution (kW/m width of oncoming wave) [8]

The world wave energy resources have been commercially estimated in more than 2000 TWh/year (10% of world electric demand) with an expected investment of 735000 M€ [9]. Comparing with the wind energy forecast (40000 MW in 2010), 2000 MW of sea energy power is expected to be installed in 2020, the most of it using wave energy [10].

The most relevant characteristics of different generation technologies are analyzed below, also mentioning their advantages and disadvantages

A. First Generation Devices

The first generation devices group is mainly composed of the shoreline technology (fixed devices). Inside this group the importance of the OWC (Oscillating Water Column) should be emphasize. This on-shore installed equipment has a turbine moved by the air flow generated by an oscillating water-column, which harness the wave energy. Nowadays, the most used turbine for this purpose is the Wells turbine, because of its unidirectional torque, regardless of which the air flow direction is. This kind of turbine's maximum performance is around 70-80% (see figure 4).

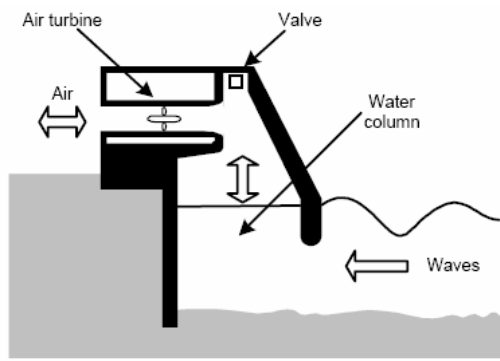


Fig. 4. Oscillating Water Column device [10]

A good example of this technology is the LIMPET (Land Installed Marine Powered Energy Transformer). It is a 500 kW rated power plant, developed and operated by Wavegen company, in the coast of Islay, Scotland. It comprises a single counter-rotating Wells turbine in which each plane of blades drives a generator rated at 250 kW. Using this kind of devices, theoretically it would be possible to obtain up to 50% energy conversion performances [11]. Apart from the coastline OWC, breakwater OWC has been developed with no further environmental impact.

Another example of this technology is the shoreline OWC pilot plant on the island of Pico, Azores, using a Wells turbine and with a rated power of 400 kW [10].

B. Second generation devices

These are the floating, semi-submerged or submerged devices, commonly the offshore ones which may have a fixed connection to the seabed or another structure. They harness the oscillating wave motion to generate electricity. Their location is usually on the continental shelf up to 150 m depth waters, no further than 12 nautical miles from the coast. The importance of this distance limit is related with the increased cost of the underwater cable installation from the wave energy device to the electric grid connection point.

Nowadays, from the power conversion train point of view, several technologies have been developed. Some of them are mentioned below:

- Oscillating movement → Fluid compression → Hydraulic turbine drive → Rotary electrical generator
- Oscillating movement → Linear electric generator (First stage of development)
- Oscillating movement → Sea water pumping to coast → Hydraulic turbine drive → Rotary electrical generator (Seadog pumping system)

There are countless patents and designs for this kind of wave energy conversion. However, just a few ones have reached the real prototype stage development, being tested in real conditions. As an example, the technology developed by the Ocean Power Technologies (OPT) company, composed of multiple buoys (PowerBuoy) and underwater transmission cable [12].

Other examples are:

- Pelamis: It involves 4 large floating cylinders connected together. As the waves pass, a pendular motion is generated, which impulses a power conversion hydraulic system. Several prototypes of 750 rated power have been tested all over the world.
- Wave Dragon: This design has a parabolic wave concentrator, which increases the water volume in a higher reservoir, to be released through Kaplan turbines later. It is expected to have a real-size prototype of 7 MW rated power installed in the west coast of Scotland in 2007.
- Energetech: OWC system (500 kW – 2 MW), installed in Port Kembla, Australia in 2005 [20].

C. Advantages and disadvantages

1) Advantages

Shoreline Devices

- Shoreline devices have far less difficulties in power grid connection than the offshore ones
- Maintenance and repair costs are lower than those for offshore devices, due to the unlikely storm damages.
- Less environmental impact than conventional tidal power plants. The visual impact may be reduced when small Wells turbine modules are installed in specific places such as breakwaters, harbour walls, etc.
- The shoreline prototypes installed a few years ago have already provided enough data to improve efficiency and reliability and to reduce the total cost.
- High availability.

Offshore devices

- There are more places suitable for wave energy conversion than those for tidal stream energy.
- The available power offshore is higher than in shoreline installation.
- Easier calculation of real energy performance in offshore devices.

2) Disadvantages

Shoreline Devices

- The coastal orography, when choosing the installation point, is essential to reach a pneumatic performance closed to the theoretical one.
- There are less suitable places for shoreline technology than for offshore one.
- Although they have less environmental and visual impact than other sea energy conversion systems, this impact is quite high. Construction works usually modify part of the coastal orography, damaging possible locations of marine species.
- Available wave energy in shoreline installations is less than in offshore locations.

Offshore devices

- Higher maintenance and repair costs, considering the use of ships, due to both in-situ works and device transport.
- Collision risk with ships and marine species.
- The environmental and visual impact will mainly depend on the specific technology used, but it could be higher than in first generation devices.
- Higher power losses and cost than in shoreline devices, because of the longer connection cables used in offshore technologies.
- The structural strength in case of sea storms is a great handicap not assessed enough so far.
- There are only few data available obtained from real-scale prototype trials.

Due to the variability of wave energy, these devices need some storing system to increase the stability of the generated electrical energy (reducing power oscillations) and to improve the power quality of its grid connection. The power plant may be forced to auto-shutdown if power quality does not fulfil the electrical grid constraints [18].

4. Ocean Thermal Energy Conversion (OTEC)

The ocean thermal energy can be harnessed by means of a thermodynamic cycle, which uses the temperature gradient between the cold deep waters and the warm surface waters. It is estimated that, the amount of solar energy absorbed annually by the oceans is equivalent to 4000 times the world energy demand in the same period [13].

The main problem with this renewable energy is the necessity of a temperature gradient higher or equal to 20°C, between the hot and cold reservoir. The higher the temperature difference, the better efficiency it will have. This requirement is only fulfilled in tropical and equatorial zones during the whole year.

The OTEC systems efficiency is not quite high because of the little temperature difference used in the thermodynamic cycles. Although the ideal energy conversion using 26 °C and 4 °C warm and cold seawaters is 8%, due to several losses final 3-4% efficiency is get [13].

Apart from thermal efficiency difficulties, long piping systems will be necessary to pump the cold water from 1000 m depth or more.

Besides generating energy, OTEC systems can also be used for cold water production, for mariculture, hydrogen production and to desalinate seawater. That is why, and due to their special conditions, in some islands this would be a valid alternative to conventional energy power plants. Furthermore, its only environmental impact consists in its small cooling effect in seawater. Other collateral effects (minimum carbon dioxide out-gassing, etc), can be usually reduced with a proper plant design [13].

There are two Ocean Thermal Energy Conversion systems:

A. Open cycles

The thermal working fluid used is the sea water. The warm surface water at around 27 °C, is evaporated at low pressure slightly below the saturation pressure. After expanding in the turbine to drive the generator, the steam turns into liquid again by the exposure to a cold deep water (5 °C) condenser (figure 6). Finally, it is returned to the sea.

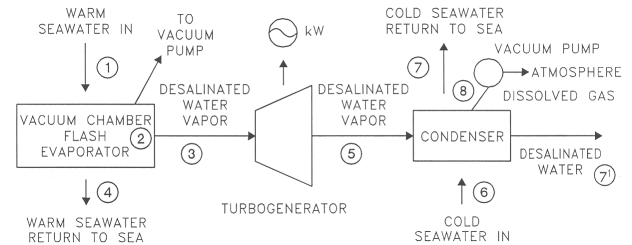


Fig. 5. Open cycle [13]

An example of this kind of OTEC is the Natural Energy Laboratory of Hawaii (HNEI), working between 1993 and 1998 with a turbine-generator of a designed output of 210 kW.

B. Closed cycles

These type of cycles use ammonia, propane, freon, etc. as thermal working fluid (low-boiling point fluids). The liquid fluid is pumped through the evaporator, where it is vaporized by the warm surface water at 27 °C. After that, it is expanded in the turbine (driving the generator) and then the cold deep water at 5 °C condenses it back to a liquid, closing the cycle (figure 7).

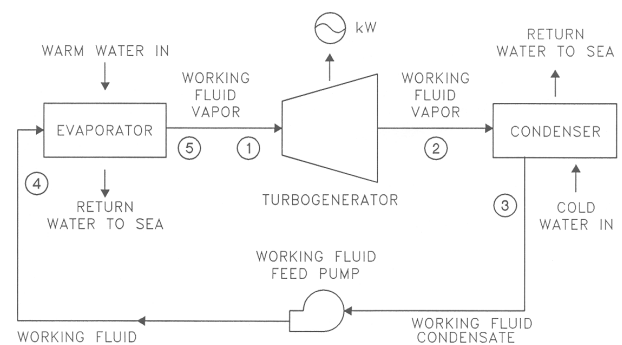


Fig. 6. Closed cycle [13]

Examples of closed-cycles OTEC are:

- Mini-OTEC: Small plant mounted in 1979 on a barge off Hawaii, producing 50 kW of gross power (net output of 18 kW).
- 100 kW gross power, land-based plant operating in the island nation of Nauru, in 1981.

C. Hybrid cycles

These cycles produce both electricity, with a closed cycle system, and fresh water, by the desalination with an open cycle system.

D. Advantages and disadvantages

The most important advantages and disadvantages of this sea energy conversion technology are stated below.

1) Advantages

- Damaging environmental effects are minimized if the cold water is discharged to the ocean at enough depth.
- Desalinate seawater, produced cold water for mariculture and hydrogen by electrolysis, are other OTEC advantages.
- Highly available energy resources.

2) Disadvantages

- The small land based OTEC plants need kilometres of piping to move a high volume of cold water from deep ocean. Its cost could be up to the 75 % of the total power plant costs. Therefore, researches show that power plants with a rated power lower than 50 MW can not compete with other energy sources. As an example, a 50 MW power plant would require a 3 km long pipe with a 8 m diameter to pump 150 m³/s of cold water [14].
- The suitable locations to harness this kind of energy are reduced to equatorial and tropical zones.
- Higher cost than other energy sources (hydroelectric, wave energy and diesel) in islands.
- Low thermal efficiency due to the low temperature difference between the cold and hot reservoir (around 22 °C).
- Although floating OTEC plants could apparently be a solution, maintenance and repair costs would also be high.
- Floating plants and piping of land based plants must withstand high stresses during storms.

5. Comparative analysis

Finally, a comparative summary of the different sea energy resources is showed in table 2, considering their advantages and disadvantages in each case. The mentioned figures must be considered as average values. The compared characteristics are the following ones:

A. Power Unit Cost

Nowadays, the unit cost of sea energy technologies is still higher than other kind of renewable energies. However, R&D trends show the installation of different pilot plants, both offshore and shoreline (also sea streams devices). Therefore, in the medium-long term, costs are expected to decrease and considering their good features, they could finally be competitive with other energy resources. Above all, OTEC systems have the highest power unit cost (as an example, see Table 2 for a 40 MW power plant).

B. Total efficiency (η)

Wave energy and tidal streams devices have the highest efficiencies of all sea energy sources. The efficiencies of the power conversion train are expected to be improved by the use of the data obtained in the installed pilot plants. As it can be seen table 2 below, the OTEC systems efficiencies is quite low, although it could be balanced by its vast available energy quantity and the possibility of producing other goods, such as: fresh water, nutrient rich cold water for mariculture and hydrogen by electrolysis.

C. Global resources

In contrast with its efficiency, OTEC systems have an enormous quantity of energy resources, far higher than tidal stream, tidal power plants and wave energy technologies.

D. Energy density

Tidal stream energy has the highest energy density, higher than the wave energy and the OTEC. Despite its highly available thermal energy, the OTEC energy density is quite low, so it is necessary a high cold water volume per generated MW.

E. Predictability

The OTEC systems hardly depend on seasonal nature to generate its rated power, so its predictability factor is higher than the others. On the contrary, the wave energy is very unpredictable in the medium-long term and with high seasonal dependence (heavier swells in winter than in summer, in warm climates). Streams are mainly produced by tides, so they are more predictable in the medium-long term and with less seasonal dependence than the wave energy.

F. Availability

The availability represents the probability of a sea energy based system to produce energy in a certain moment, and is directly influenced by the maintenance and repair periods. It must be consider that tidal stream and OTEC conversion technologies are still under development (pilot plants), so the real operation data is not available yet. The data showed in table 2 are based on some real-scale prototype tested so far, they are not average values of each type of energy source.

G. Operation and Maintenance cost

The operation and maintenance cost of conventional tidal power plants is the lowest of all sea energy conversion devices. Mainly, it is due to the working experience of La Rance (France) tidal power plant, connected to the grid during decades. While Cost for OTEC is estimated in 1.5% of capital cost [13], wave and tidal stream energies costs mentioned are only applicable for some of the technologies tested up to now.

	Power Unit Cost (€/kW)	Total Efficiency (η)	Global Resources	Energy Density	Predictability	Availability	Operation & Maintenance Cost	Environmental and Visual Impact	Future Development
Tidal Power Plants	1500 (1985 year) [1]	25% [1]	105.4 TWh/y (in Europe [1])	Very High	High	High 90%[1]	Low [1]	Medium-High	Low
Tidal Stream	2000 [6]	30% [4]	21900 TWh/y [2]	Very High	High	-	High [15]	Medium-Low	Medium – High
Waves Shoreline	2240 [10]	25% - 50% [7]	2000 TWh/y [9]	High	Low	High 96% [10]	High 48 €/kW/y [10]	Medium	Medium – High
Waves Offshore	1920 – 3200 [10]	50% [16]		High	Low	High 90% [10]	Medium 30 €/kW/y [10]	Medium-Low	High
OTEC	7600 [19]	3% – 4% [13]	87600 TWh/y [17]	Low	Very High	-	Low 1.5% [13]	Low	Medium

Table 2. Comparative table of different sea energy resources

H. Environmental and Visual Impact

As it has been previously mentioned, the most environmentally damaging technology is the conventional tidal power plant. The other ones have mainly a visual impact, over commercial maritime routes or coastal ecosystem, but not as higher as the tidal power plants.

I. Future development

Conventional tidal power plants are not probable to be extensively installed, due to its important disadvantages: high cost, construction period of several years, few proper locations and the already mentioned environmental impact. Because of this, energy development policies promote other renewable energies (such as solar or wind energy) and in the medium-long term wave and tidal stream energies are expected to be equally promoted as well. On the other hand, the OTEC systems will only be possible in those specific areas (mainly islands) when the temperature gradient is 20 °C, at least. Not only for power generation, but also for different productions.

Although 5800 MW of marine renewable power is expected to be installed between 2004 and 2008, only a small percentage of it will be composed by wave and tidal power technologies, due to their less development compared with offshore wind energy. This energy is rapidly growing nowadays, but the wave and tidal energy could have the same trend from around 2010 [6].

6. Conclusions

This paper analyzes a brief description of the general characteristics shown by the different technologies proposed nowadays for harnessing the sea energy. In each technology, advantages and disadvantages are mentioned related to different factors, such as technology efficiency, availability, environmental impact, etc. Finally, a comparative analysis is done to get an idea about the state-of-the-art of the sea energy conversion systems.

References

- [1] Fernandez, P., “Energía Maremotriz”. University of Cantabria, Spain.
- [2] “UK, Europe and Global Tidal Stream Energy Resource Assessment”, Black and Veatch Consulting Ltd., 2004.
- [3] “Status, Research and Development Priorities; Wave and Marine current Energy”, DTI report number FES-R-132, AEAT report number AEAT/ENV/1054, 2003.
- [4] “New Turbine can Extract Energy from Flowing Water”, The Christian Science Monitor, May 2001.
- [5] Kowalik, Z., “Tide Distribution and Tapping into Tidal Energy”, Institute of Marine Science, University of Alaska, 2004.
- [6] Meisen, P. and Hammons, T., “Harnessing the Untapped Energy Potential of the Oceans: Tidal, Wave, Currents and OTEC”, IEEE 2005 General Meeting, San Francisco, 2005.
- [7] Fernandez, P., “Energía de las Olas”. University of Cantabria, Spain.
- [8] “Wave Energy Utilization in Europe. Current Status and Perspectives”, Centre for Renewable Energy Sources (CRES). 2002.
- [9] Thorpe, T.W., “An Overview of Wave Energy Technologies: Status, Performance and Costs” & “Wave Power – Moving Towards Commercial Viability”. IMECHE Seminar, London, UK, 1999.
- [10] “WaveNet; Results from the Work of the European Thematic Network on Wave Energy”, European Community, March 2003.
- [11] “WaveGen; Islay Limpet Wave Power Plant”, The Queen’s University of Belfast, April 2002.
- [12] www.oceanpowertech.com
- [13] Vega, L.A., “Ocean Thermal Energy Conversion (OTEC)”, Hawaii, USA, December 1999.
- [14] “Ocean Thermal Energy Conversion and the Pacific Islands”, SOPAC Miscellaneous Report 417, March 2001.
- [15] Bahaj, A.S. and Myers, L.E. “Fundamentals Applicable to the utilization of Marine Current Turbines for Energy Production”, Renewable Energy 28, 2003.
- [16] Bedard, R. and others, “Offshore Wave Power Feasibility Demonstration Project”, EPRI Global WP 009, January 2005.
- [17] “Potential and Future Prospects for Ocean Thermal Energy Conversion (OTEC) in Small Islands Developing States”.
- [18] Pontes, T., Neumann, F., and Sarmiento, A., “European Thematic network on Wave Energy”, Brighton, October 2002.
- [19] Takahashi, P. and Trenka, A., “Ocean Thermal Energy Conversion”, UNESCO Energy Engineering Series, John Wiley & Sons Ltd., 1996.
- [20] www.energetech.com.au
- [21] www.marineturbines.com