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WAVE ENERGY CONVERSION SYSTEMS

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Abstract

It is a consensus to widespread use of renewable sources for disposal of environmental impact caused by fossil fuel consumption, and moreover to remedy of fossil fuels depletion. Wave power is a renewable kind of energy. Worldwide potential for wave power is enormous. Ocean appears to be an important source of wave energy. Various systems are developed and some new projects are implemented on this subject. Therefore, in this study has been presented the wave energy conversion systems in detail with a classification and various aspects.

Keyword: *Wave energy, conversion system, ocean, sea*

1.INTRODUCTION

Everyone is responsive to the problems caused by increasing world population, steadily growing and diversified consumption habits. Changing life style influences electricity and energy consumption per person, which plays an important role to depletion of fossil fuels, and some negative environmental impacts of fossil fuel use (greenhouse effect, acid rain etc). Diversification of energy sources, and increasing use of renewables with minimum negative environmental impacts seem to be a plausible solution for providing sustainable life-cycle and continuous improvement.

Approximately three-quarters of the earth's surface are covered by lakes, seas, and oceans, which offer various renewable energy sources. Generally, the energy potentials of marine are classified in five groups: wave energy, tidal energy, ocean thermal energy, ocean current energy, and salinity gradient energy [1]. In other classification, the marine (ocean) energy can be divided into two types; thermal energy from the sun's heat, and mechanical energy from the tides and waves [2, 3]. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. Formation of ocean mechanical energy is different from ocean thermal energy. Tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. The electricity conversion of both tidal and wave energy usually involves mechanical devices [3].

Wave, tidal and ocean energy technologies are just beginning to reach viability as potential commercial power sources [4]. Renewable energy analysis show there is enough energy in the ocean waves to provide up to two terawatts of instantaneous electricity, which is twice the electric generating capacity currently available throughout the world [5]. Electricity power generation from wave has a large potential to contribute to our electric energy production, and today, many wave power projects are close to be commercialized [6].

The wave energy conversion subject is new, essential, and in development stage. Researches on this subject are increasing in recent years. Therefore, this study focuses on wave energy. The various wave energy Conversion Systems are presented with the consideration of different aspects, a classification relevant to the topic. Moreover, the advantages and disadvantages of the Systems are mentioned.

2. WAVE ENERGY

Wind generated waves starts to develop at wind speeds of approximately 1 m/s at the surface, where the wind energy is partly transformed into wave energy by surface shear [7]. The formulation of the propagation of waves is based on the study of D'Alembert who introduced the first linear wave equation. The first order descriptions of water waves was initially obtained by George Biddell Airy. Therefore this is known as the Airy wave theory. Further developments were analyzed by Sir George Stokes to adequately describe waves with increased steepness ratio (the ratio of a wave's height to its length), and a new theory the Cnoidal wave theory was developed to accurately describe shallow water waves [8]

Linear wave theory is the core theory of ocean surface waves [9]. According to this theory, wave power could be determined by wave height, wave lenght, and water density. This mathematically could be described as in [10, 11]

$$P = \frac{\rho g}{64\pi} h^2 T \qquad (1)$$

Where P is the wave energy flux per unit wave crest length (kW/m); ρ the mass density of the water (kg/m^3); g the gravitational acceleration (m/s^2); h the wave height (m); T is wave period (s).

The design of ocean wave energy converters is based on the utilization of either the speed of the seawater, the changes in the wave surface angle, or the changes in the hydrostatic or total hydrodynamic pressure of the waves [12]. There are mainly three types of wave energy conversion technologies;

-One type uses floats, buoys, or pitching devices to generate electricity using the rise and fall of ocean swells to drive hydraulic pumps.

-A second type uses oscillating water column (OWC) devices to generate electricity at the shore using the rise and fall of water within a cylindrical shaft. The rising water drives air out of the top of the shaft, powering an air-driven turbine.

-Third type is a tapered channel, or overtopping device can be located either on or offshore. They concentrate waves and drive them into an elevated reservoir, where power is then generated using hydropower turbines as the water is released. The vast majority of recently proposed wave energy projects would use offshore floats, buoys or pitching devices [13].

2.1 Classification of conversion systems

The sea wave's motion can be converted into mechanical energy by using proper wave power mechanisms. There are currently about 40 types of mechanisms for exploiting the energy available in waves, several of which are now being constructed [14]. There is a large number of concepts for wave energy conversion; over 1000 wave energy conversion techniques have been patented in Japan, North America, and Europe [15, 16]

The mechanical power created from these systems either directly activates a generator or transfers to a working fluid, water, or air, which then drives a turbine/generator [1]. These devices are generally categorized by location installed and power take-off system [14, 16]. These mechanisms can be lying on the bottom of the sea, on the shoreline and on sea level [14]. Locations are shoreline, nearshore and offshore. Wave energy conversion (WEC) systems can be classified according to the following criteria [17].
-According to the installation site as onshore, onshore-nearshore, and nearshore-offshore
-According to the energy capture system as turbine (driving fluid may be water, oil, or air) based, and motion (linear or rotational) mechanism based systems.
-According to operation principle (power take-off mechanism) as
Overtopping devices, Oscilating water columns, and Wave-activated bodies Figure 1 [18, 19].

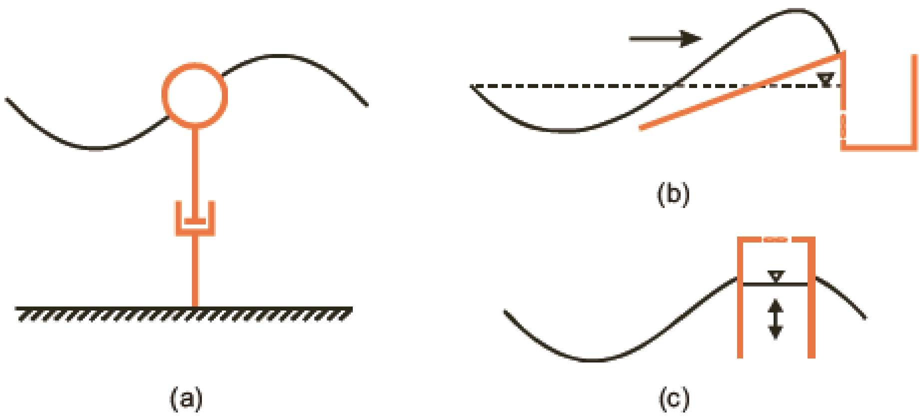


Figure 1: Classification of wave energy devices [a) Wave activated bodies, b)Overtopping devices , c) Oscillating water columns]

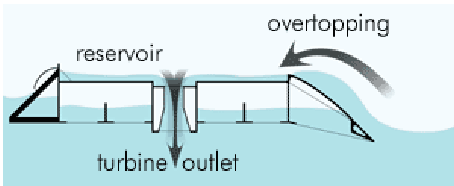
Classification based on power take-off mechanism and description of these systems is following presented.

2.2 Overtopping (wave dragon) system

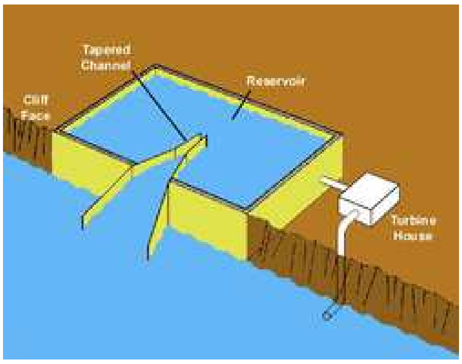
These kinds of devices operate with the principle of the difference between the levels of the wave crest and the wave trough. The difference between the water levels in the basin and the sea is used by a hydrokinetic or a low-head turbine [12]. Wave Dragon is a simple construction and only the turbines are the moving parts [14]. This is similar to the tidal energy Conversion System. They are entitled as well as channel device or tapered channel.

Channels may be used near the shore to the wave energy into an elevated reservoir. Then as the water flows back out of the reservoir a standard hydroelectric water turbine is used to generate electricity, Figure 2a [4]. In the tapered channel application, the waves are guided through a tapered channel, Figure 2b [15, 16]. Overtopping device elevates ocean waves to a reservoir above sea level where water is let out through a number of turbines and in this way transformed into electricity, Figure 2c [20]. Figure 2d shows a photograph of the Wave Dragon system [14].

a. Channel System



c. Overtopping principal



b. Tapered channel principal

d. Wave Dragon system nearshore

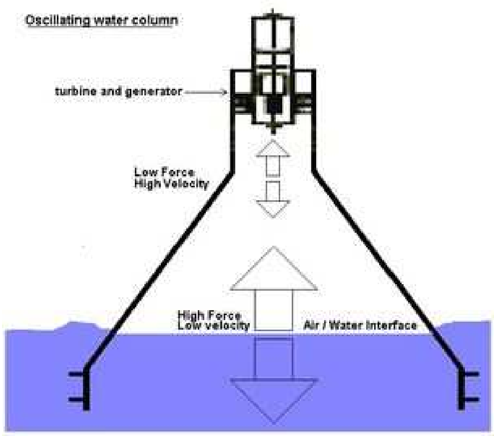
Figure 2: Overtopping (tapered channel) wave energy Conversion System

2.3 Oscillating water column

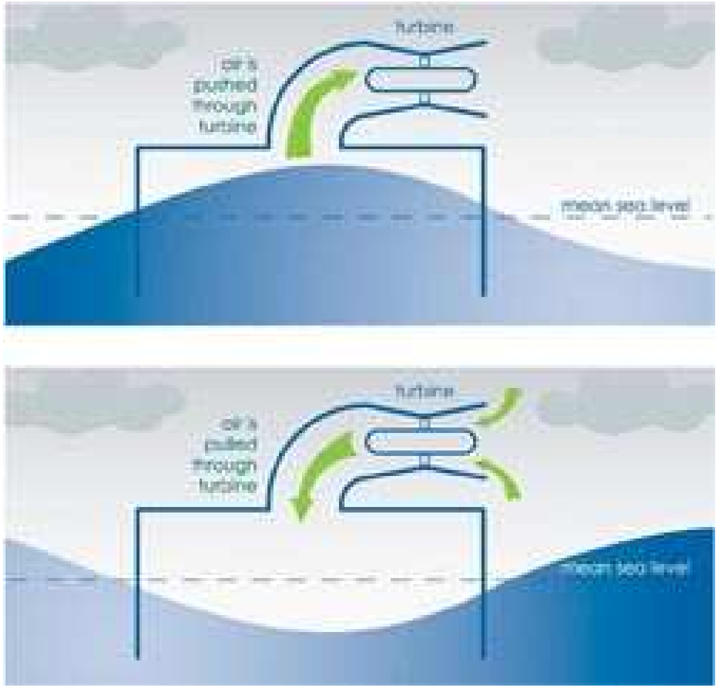
This system consists of a chamber built in shoreline cost, Figure 3a [14]. An oscillating water column (OWC) is a partially submerged, hollow structure that is installed in the ocean [21]. The motions of ocean waves, which create a column of water, push an air pocket up and down [22]. The pushed air drives a turbine and conversion system to generate electricity. Air is forced out of the column as a wave rises and fresh air is drawn in as the wave falls. This movement of air turns a Wells turbine at the top of the column, Figure 3b [23].

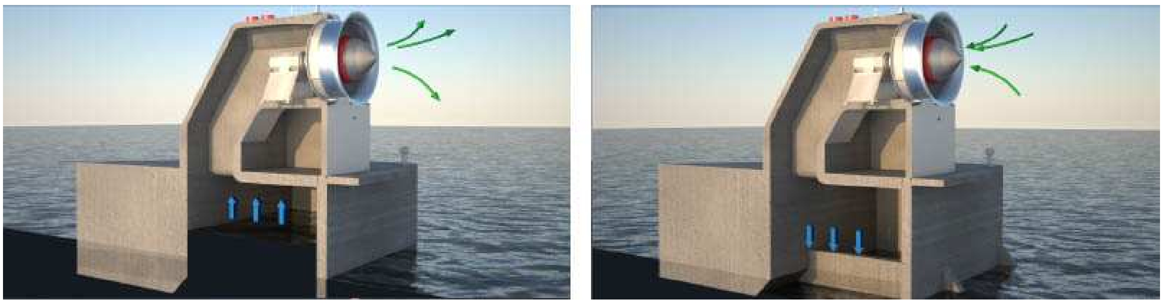
There is an air tank above sea level. As waves move up and down, the air is compressed and then drawn back to drive a turbine [16]. The air tank has a chamber with one end open to the sea the other end vented to an air turbine [24]. As the waves rises within the Oscillating Water Columns, it replicates the action of a piston, driving a column of air ahead of it and past the turbine. As the wave recedes the opposite effect is experienced. Air is sucked back into the OWC and past the turbine, Figure 3c [25]. The movement of air through a system of valves drives the rotating motion of the air turbine, which is located in an aperture on top of the chamber [12].

The OWC concept has been extensively studied over the last thirty years and proved the extraction of energy under real sea conditions. The shoreline location means a lower level of energy resource limits the installation of large numbers of devices [26]. Moreover, this pneumatic system can be very noisy unless a silencer [14].



a.Oscillating column of water system principal   b. Oscillating column system schematic





c.System schematic for two way turbine function
Figure 3: Oscillating water column system

2.4 Wave activated solid bodies with buoys

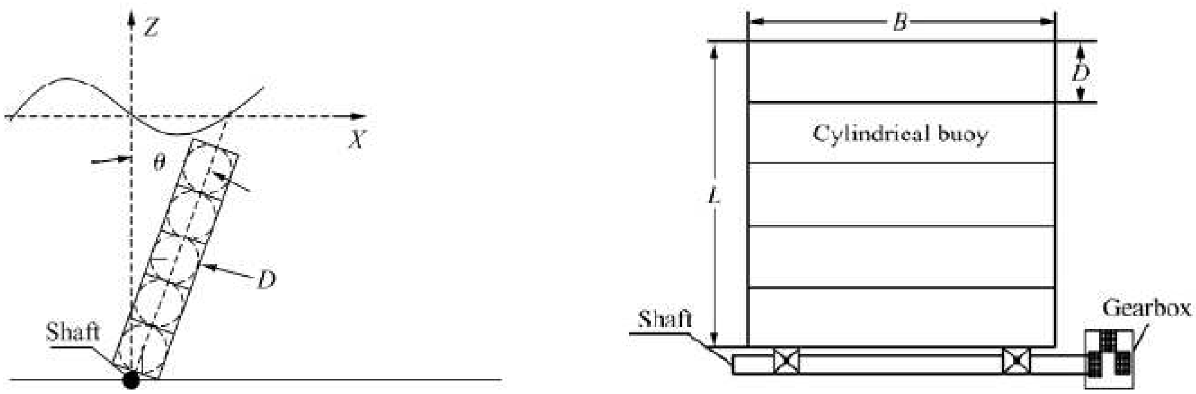
Main equipment of this system is floating buoys, which can be divided into horizontal and vertical types. Buoys systems can be suitable for onshore and particularly offshore applications of wave power into electricity. There are various types of the wave activated solid bodies systems, which are classified and presented below.

2.4.1 Horizontal buoys

Buoys are mounted with hinges on the seabed. Most of horizontal buoys uses semi-submerged cylinders linked by hinged joints. Inside each cylinder, there is a hydraulic ram which pumps high-pressure oil through hydraulic motors. The hydraulic motors in turn drive electrical generators inside the cylinder. Many of these cylinders can be combined and then the energy can be fed to an underground sea cable and back to shore [4]. Horizontal buoys can be categorized into bottom and top- hinged system.

2.4.1.1 Bottom hinged flap model

The bottom hinged flap model has been given in front and side view in Figure 4 [27].



a.Side view b.Front view

Figure 4 The bottom hinged flap model

Fixed type pendulum wave energy converter is a kind of movable body type wave energy converter, which has high energy conversion efficiency [28]. The movement of the flap can drive a hydraulic pistons which push high pressure water onshore via a subsea pipeline to drive a conventional hydro-electric turbine [29] Figure 5 [30], an air compressor via the gear transmission system Figure 6 [31], or a flywheel system via freewheel mechanism with gear box and generator, Figure 7 [32].

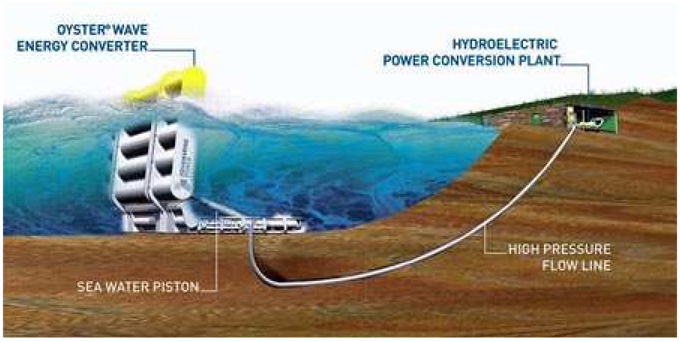


Figure 5 Flap driven hydraulic pump system

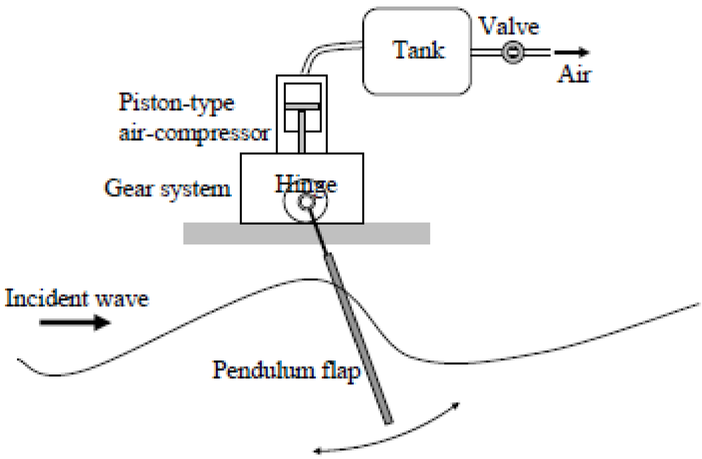


Figure 6 Compressed air generation system with pendulum type wave energy converter

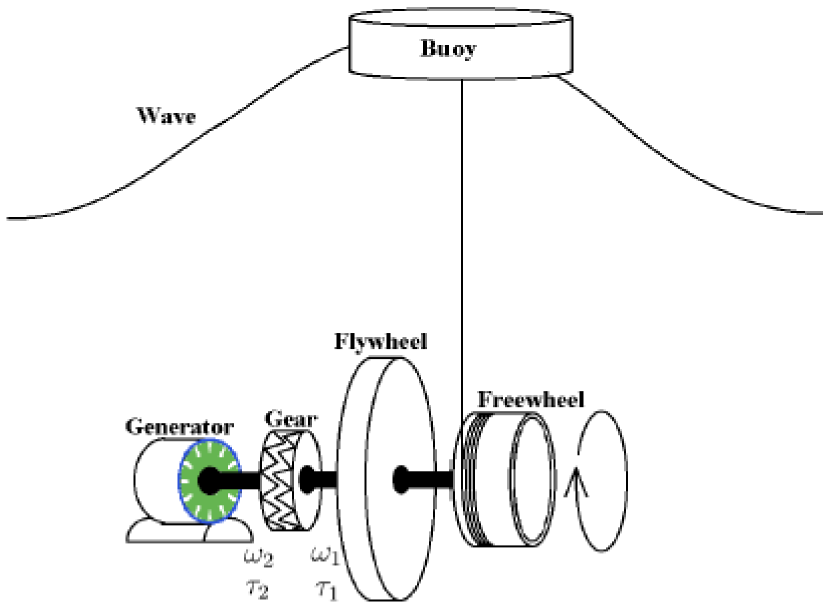


Figure 7 Flywheel system wave energy converter

2.4.1.2 Top-hinged flap model

This system is implemented two distinct forms called respectively pendulum flap and wave clapper. Flap pendulum system consist of a parallelepiped concrete box, which is open to the sea at one end, as shown in Figure 8 [14].

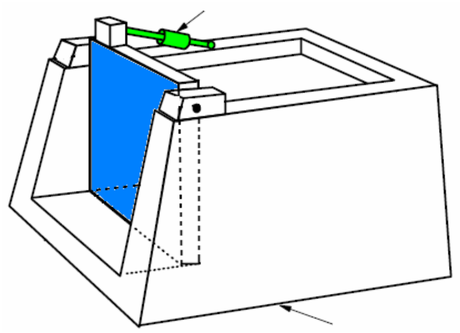


Figure 8 Pendulum flap system

The Wave Clapper is designed for places with space restrictions (not enough space to implement the large-scale floaters). Shape and form of Wave Clapper enables to put the floaters with very small spaces between one another and prevent the need in safe gaps between the floaters, Figure 9 [33].

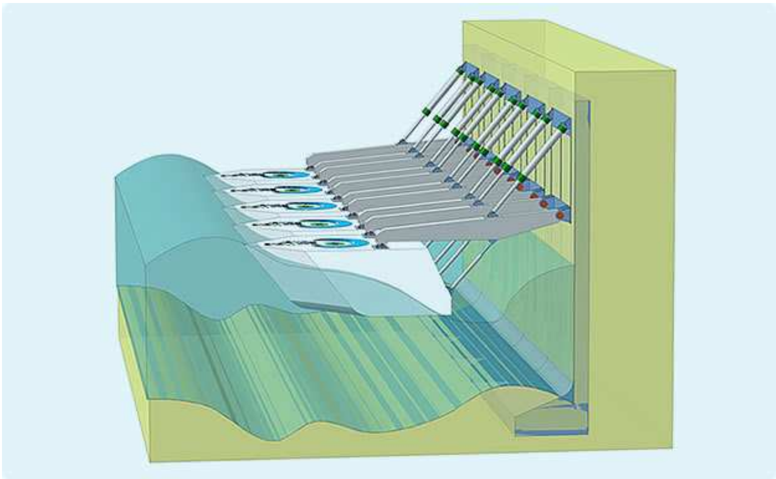


Figure 9 Pendulum wave clapper system

A typical sample of a horizontal buoy is the Pelamis wave energy converter. In Pelamis sea snake system, semi-submerged cylinders linked by hinged joints Figure 10 [34][71, 35, 36]

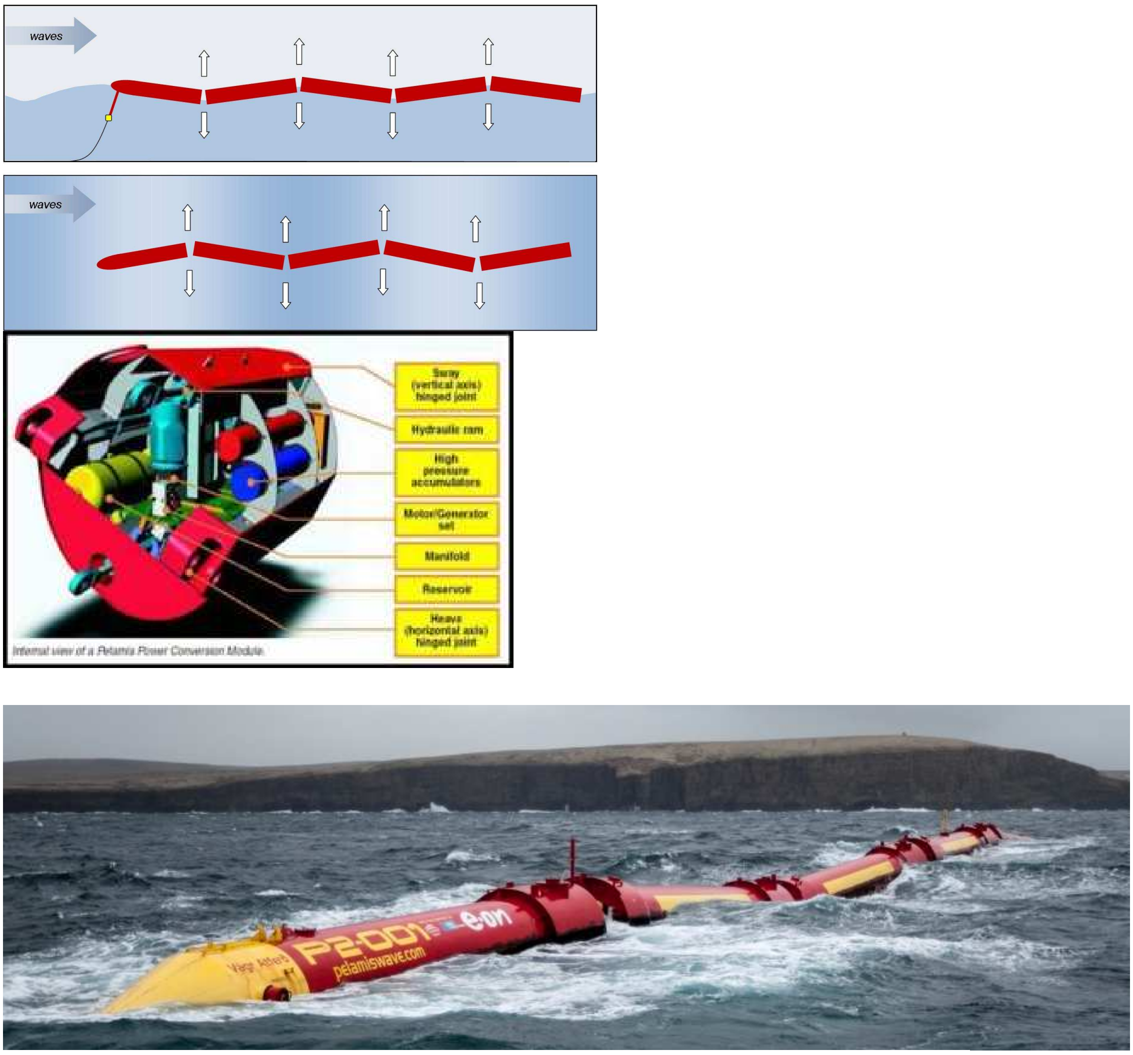
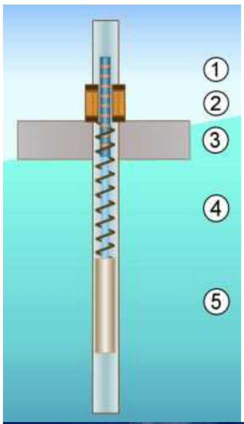


Figure 10. Pelamis wave energy converter

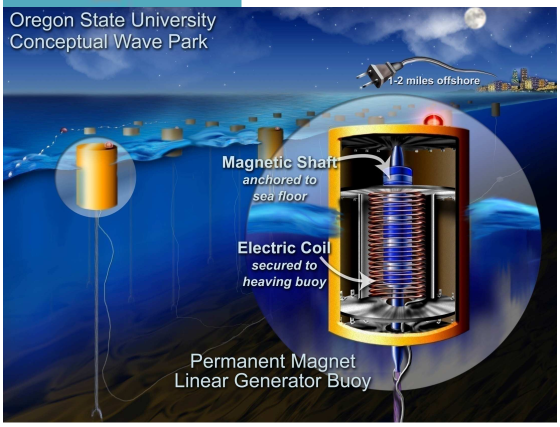
2.4.2 Vertical buoys system

Vertical buoys can also be used in a similar manner to move a piston up and down which contains a permanent magnet. The magnet is surrounded by a copper wire coil. As the magnet moves back and forth through the coil an electric current is automatically generated. Floating buoys can generate energy from the bobbing or pitching motion caused by the waves [4]. This system consists of two buoys (two floating cylindrical tanks) [37]. The current is produced directly without the need of a generator by vertical buoys system [4].

A pendulum mass hanging beneath a spring moves anticyclical up and down. This mass drives the direct-connected magnets that are inducing an electrical current while moving through the inductance coils, Figure 11a [38]. This system doesn't need the use of pneumatic and hydraulic conversion steps, Figure 11b [39, 40].



1. Magnets
2. Inductance coils
3. Floating disc
4. Spring
5. Pendulum mass



a. Brandl motor b. Oregon State University concept

Figure 11 Vertical buoys with direct magnet system

There ar many other applications in vertical buoys for wave energy conversion such as PowerBuoy, which consist of a float, spar, and heavy plate as shown schematically in Figure 12 [41, 42]. The float moves up and down the spar in response to the motion of the waves. The heavy plate maintains the spar in a relatively stationary position. The relative motion of the float with respect to the spar drives a mechanical system contained in the spar that converts the linear motion of the float into a rotary one. The rotary motion drives electrical generators that produce electricity which transmitted due to submarine electric cable [41]

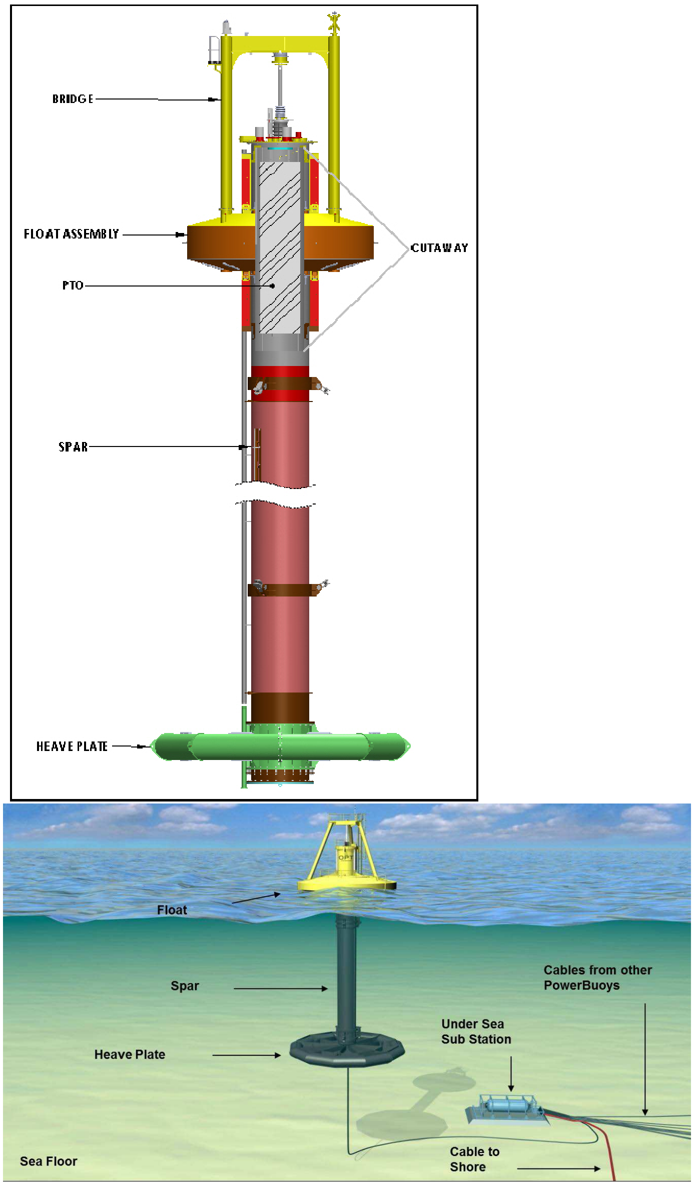


Figure 12 Schematic of Powerbuoy for utility project

3.DISCUSSION

All wave energy installations are comprised of three fundamental parts: the working medium, the power converter, or power take-off, and the mooring system. The working medium is in immediate contact with the water and performs movements. The working medium transforms the energy of the water into some other kind of energy, making it more convenient for further conversion. The power take-off is designed to convert the energy accumulated by the working medium into the kind of energy suitable for transmission over distance, or for immediate use. The mooring system keeps the wave energy converter in place [12]. A variety of technologies have been proposed to capture the energy from waves; however, each is in too early a stage of development to predict which technology would be most prevalent in future commercialization. It seems more critical to investigate of offshore applications of developping Technologies, which can be classified as terminators, attenuators, point absorbers, and overtopping devices [43].

Deploying WECs in off-shore locations introduces artificial structures in the ocean topography. It has also been observed that the WECs can actually reduce shore erosions as they take the energy out of the waves as they reach the shore and waves are available almost all the time [44].

OWC system transmits the wave elevation to pressurization of the air. Pressurized air drives a turbine-generator for electricity production. Turbine-generator parts are similar to wind energy conversion system. There is two-stage energy conversion in OWC system. Hence, total system efficiency is influenced in two different stages, one is during conversion from water column to air, and the other is from pressurized air to electricity. Special turbines are generally used in these systems such as Wells turbine. Air is considered a compressible gas. This can lead some unstable behavior of energy form which is referring to the turbine. Some special precautions should be taken carefully to capture air into the system and cycle continuity.

There is not a space requirement in valuable coastal and terrestrial areas because the system is settled to the sea. The system seems maintenance easier and less costs because of absence of complexity and simple and robust mechanical parts. Moving parts are housed outside of the water. This can cause a greater lifetime of the material. This system can be built near shore for easy access to the power grid and for maintenance.

There is a certain affinity between the overtopping system and tidal energy conversion system. Low-head turbines are generally used in Overtopping system. Water is primarily deposited in dam-like structures. Thus there is the potential energy stored. This potential energy of water drives turbines and combined generators for electricity production. The most important issue that must be eliminated is to find the suitable water basins areas. Resemblance of Overtopping system to the classic hydro-electric plants seems to be an important advantages. The technology is good known and with solved problems.

Buoyancy force/oscillating body systems are subject-specific which was developed only for wave energy conversion. This conversion system emerges in different variations. It is possible the electricity production is directly due to dynamos which sense up and down movement of the wave such as Brandl generator. This up and down movement may be taken by worm gear-pinion which converts linear forces to rotational movement. Due the rotatioanal achs it is possible to drive a conventional generator. Moreover, hydraulic linear actuator can be used to pressurize hydraulic fluid which can drive a hydraulic motor combined classical generator. However, special care should be taken for operation and maintenance if hydraulic systems are used as intermediate converter. In addition, it is possible to pump the water to a higher level thanks to hydraulic actuator.

The conversion of ocean waves into low-cost electricity has enormous potential, but with some uncertainties. Therefore, it is essential to predict the potential environmental impacts. The following expectations are underlined by Scientists during the study of impacts of wave energy conversion systems [45, 46, 47].

-Waves, streams and physical impacts on littoral transport
-Elektromagnetic field effect and changes in migration in fish types
-Habitat effect
-Fouling community effects and interactions
-Aggregation effects in pelagic environment
-Planktonic community
-Effect of Benthic disturbance and Benthic-pelagic coupling
-Electromagnetic field effects on marine mammals and seabirds, change in migration entanglement.
-There could be significant wave reduction (10-15%) resulting from wave energy production, with possible beach effects (e.g., changes to sediment transport processes.
-In the Pelagic Habitat, buoys will likely have a minimal impact on phytoplankton, but positive effects (through aggregation) on forage fish species
-Wave energy development can affect community structure for Fish and Fisheries through changes in species composition and predator effects (e.g., attraction of predators that were previously absent).
-All devices can cause the seabed to be disrupted by drilling and running of cables to the shoreline
-Sounds pollution
-New hard structures in pelagic and soft sediment environments
-Beach characteristics may affect beach spawning fishes such as the Surf Smelt or Night Smelt who spawn on the beach slope and deposit their eggs beneath the surface of the sand.
-Displacement of safe transit lanes for ships.

The positive aspects of the wave energy can be listed as follows:

- Water is capable of transferring a great deal of kinetic energy as compared to wind energy systems. Consequently even small wave energy devices are capable of producing a great deal of energy.

-Wave energy devices are usually low profile and so do not provide much of a visual distraction if placed off-shore.

-A big advantage of wave energy is simply its potential. Our planet is mostly ocean and so the capacity for waves as a renewable energy source is enormous [4].

-Wave energy has no greenhouse gas emissions [48].

The negative aspects of wave energy can be gives as:

-Wave energy has its share of challenges. Establishment of initial systems shows some difficulties because ocean environments are inherently changeable.

-Wave energy device must be made incredibly durable in order to survive harsh ocean conditions such as storms.

-They are either in the ocean or offshore which means that any electricity which is generated must be transferred, usually via undersea cable back to land where it can be used.

-The laying and maintenance of the electric cables can add significantly to both initial costs and maintenance costs [4].

4. CONCLUSION

One of the most promising sustainable sources is wave energy [3]. Moreover, wave energy presents different options for energy conversion. However, a lot of these options are in their development phase. Hence, some difficulties, which must be eliminated, appear in initial phases. Many of these existing technologies seem to be very complex and expensive devices with a poor mass to output power ratio. In most cases, they are difficult to scale down or use offshore and on shorelines [3]. The potential environmental impacts must be investigated within a broad frame. Furthermore, it is difficult to keep it safety in extreme weather conditions such as storm and typhoon. Despite all these, if the designs may achieve the disposal of the possible environmental impacts and installation difficulties, utilization of wave energy can open the clean and renewable way of the relatively and substantially cover of world energy deficits.

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