

**Deployment of Ocean Energy Technologies: Scope, Challenges & Opportunity**Ashokkumar A. Parmar¹, Ankit P. Shah², Paresh S. Chaudhari³¹Electrical Department, B. & B. Institute of Technology, V. V. Nagar, parmarashok2002hod@gmail.com²Electrical Department, B. & B. Institute of Technology, V. V. Nagar, ankitbbit@yahoo.co.in³Electrical Department, B. & B. Institute of Technology, V. V. Nagar, paresh_6612@rediffmail.com

Abstract — The energy from ocean wave is a largely untapped resource that could play an important role in electricity future as it had become one of the most challenging technological problems of the beginning of the 21st century to extract of wave energy. But it is more consistent and predictable than other renewable resource as wind and solar. Hence significant growth has occurred in the number of devices developed for ocean energy conversion since 2003. Multiple countries are now becoming involved in technology research and development. As many of these technologies near commercial deployment, some governments are proposing market support policies to reduce the current cost gap and help accelerate the rate of commercialization. Although several pilot projects have been successfully deployed worldwide, and some are grid connected, the economic production of electric power from wave energy remains to be demonstrated. A key path forward will be integration of smart technologies that harness vast amount of sensors and meteorological data to support wave farm operations.

The purpose of the paper is to develop an understanding about the various technologies used in the field of wave power technology with the help of insight of principles employed in devices used in harnessing wind power energy and with the examples of deployment of devices, incorporated by leading developers, onshore, near-shore and offshore. The technology is still under development and the emphasis is to develop sustainable technology with minimization of impact on environment and ecological balance, at the time to improve the factor of extracted power from wave having enormous power potential.

Keywords- Ocean wave, Wave energy convertor (WEC), On shore technologies, Offshore technologies, attenuators, oscillating water column, Overtopping, Point absorbers, Submerged Pressure Differential

I. INTRODUCTION

The most obvious form of ocean energy is the power of waves. For energy conversion, wave power can be captured at different locations viz. onshore, near shore and offshore. Offshore systems utilize different properties of motion of the sea water waves either to create an electrical charge with a pump and a floating bobber or buoy, or to operate hydraulic pumps within the joints of a floating device. The pumps pressurize the water and send it to turbine which is coupled to the electric generator. Onshore techniques include the Pendular, the Tap Chan and the oscillating water column. The Pendular uses a flap swung back and forth by waves to power a pump and generator. The Tap Chan is a tapered channel that forces waves higher and thus feeds water into a reservoir above sea level; this water then is used to turn a turbine coupled with electric generator. In case of partially submerged oscillating water column, waves are directed into an opening and compress the air column above the water, the water is then forced through a turbine; as the wave comes back, the returning water exercises a pulling force on the air and the air passes through the turbine once again. As almost all WECs prevailing in the market, based on these principles, the deployment of these devices at different locations viz. onshore, near-shore and offshore will be presented here.

II. WAVE CREST ENERGY : POWER POTENTIAL & CHALLENGES**2.1 Power Potential of Wave Crest:**

The power generating capacity of the waves can be understood by the fact that the wave energy around the British Isles is equivalent to three times current UK electricity demand. It is technically possible to convert a sizeable fraction of this wave energy to electricity. 50-90TWh of electricity per year can be recovered under current technical and economical constraints. This amounts to 14-26% of current UK demand. In addition to UK, Ireland, France, Spain, Portugal and Norway possess various potential sites off the coast. Pacific coastlines of North and South America, Southern Africa, Australia and New Zealand are also highly energetic. There is conservative estimate by the World Energy Council that

the market potential for wave energy to be in excess of 2,000TWh/year. Looking into the global resource map, provided by M/s ABP Marine Environmental Research Ltd, potential to generate wave energy potential can be seen. Map shows areas with yearly averages of over 15kW per meter which is threshold to generate wave energy at competitive prices

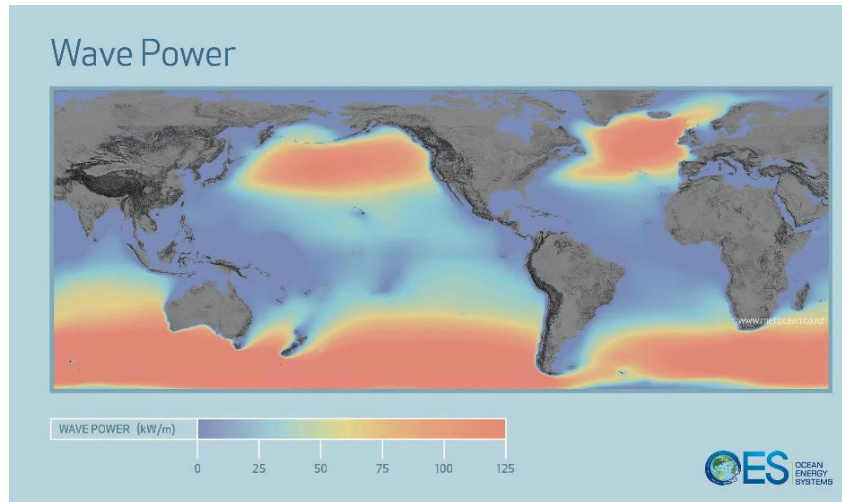


Fig.1 Global annual mean wave power distribution (Courtesy:
http://www.irena.org/.../Publications/IRENA_Ocean_Energy_report_2014.pdf)

2.2 Wave Energy Challenges: Though in the theory of generating electricity from wave power looks lucrative, there are environmental concerns related to it like any other energy generation technologies. However these impacts are dependent on several variable or diverse factors including site natural characteristics. Apart from above there are certain technological hurdles due to new technology, which are to be addressed in the future development.

2.3 Technological Challenges: Wave energy technology is more difficult than wind technology. There are few shoreline who had been commissioned in 1999(Pico) and 2000 (Inlay) for which the data is available about the survival. However there is either no or very little experience of maintenance is available. The enough data pertaining to the reliability and survival under extreme condition in real open Ocean is also not available.

2.4 Economic Challenges: There is no availability of reliable information on costs and economics. For most technologies, the capacity factor: annual-averaged power divided by rated power, is similar to wind (~0.3). As far as cost of energy is concerned, the unit cost of electricity from waves ranges between that of wind and large PV Power generations.

2.5 Environmental impacts of ocean energy. [5], [7]

2.5.1 Factors affecting Environmental Impact: The impacts also are technology specific and depend upon the type of technology is used for wave power extraction. The exhaustive estimate of impact will also depend upon the project cycle or project phase which consists of installation, operation and decommissioning. One more factor contributing into assessment of environmental concern analysis is the magnitude of the project whether it is prototype array or of wave power generation farm for which the impacts are being assessed.

2.5.2 Environmental Impacts: Here are some issues which are being enlisted in the form of receptor-who is affected by these issues, stresses- that are causing environmental concerns and the effect which the stresses impose on the receptors.

1) Receptors:

- | | |
|---|--|
| (a) Physical environment Pelagic (water column) habitat | (b) Benthic (sea floor) habitat Fish and fisheries |
| (c) Marine birds | (d) Marine mammals |
| | (e) Humans (users) |

2) Stressors : Individual or cumulative effects may be due to:

- | | |
|--------------------------------------|----------------------------|
| (a) Physical presence of the devices | (b) Chemical effects |
| (c) Lighting Acoustics | (d) Electromagnetic fields |

3) Effects and ecological issues

- Alteration of currents and waves due to the energy extraction and or physical presence of the devices.
- Alteration of substrates and sediment transport and deposition which may alter coastline processes and morphology.

- Benthic habitat disturbance or destruction
- Water contamination due to e.g. effluent or waste discharge, oil leaks
- Collision, strike, entrapment and entanglement of marine invertebrates, fish and mammals and birds with the equipment.
- Interference with animal movements and migration
- Displacement of marine species
- Noise disturbance
- Effects of electromagnetic on fish (sharks, rays and skates) orientation and reproduction

III. WAVE ENERGY CONVERTERS / TECHNOLOGIES

Wave power technologies are not very old due to which a little work in the field is done till date. As per the latest technological advancement in wave power technology, these can be categorized or characterized in several ways as per choice of study. The following are the ways in which these can be discriminated:

3.1 Differentiation on the basis of Method of Capturing: This differentiation is made on the basis of the device or technology used for capturing wave energy. This is the most popular categorization method. Four categories of wave energy technology exist: attenuators, point absorbers, overtopping terminators, and oscillating wave column (OWC) terminators. Point absorbers and attenuators capture wave energy as they are placed in the path of the wave. Attenuators are situated parallel to the waves and energy is captured over the surface area. Point absorbers are moored to the sea bed or float near the surface, collecting wave energy from all directions. Terminators restrain wave motion and capture energy through long arms. OWC terminators capture water from an opening into a partially submerged platform and let that water rise in an air column. The air is compressed, which drives a turbine to generate electricity.

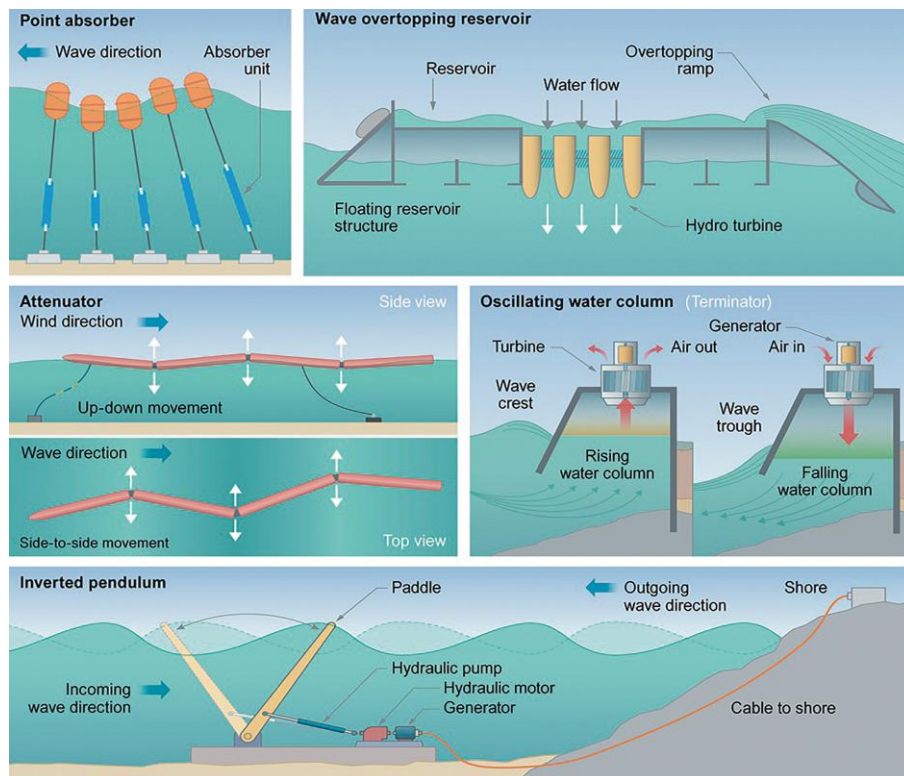


Fig.2. Major Devices of wave energy converters

http://www.irena.org/.../Publications/IRENA_Ocean_Energy_report_2014.pdf

3.2 Differentiation on the basis of Location: These technologies can be differentiated on the basis of location where the energy capturing activity is being done. There are mainly three such locations names Shoreline or Onshore, near-shore and offshore.

3.3 Differentiation on the basis of Power take-off System: Once energy is captured by WEC (Wave Energy Converter) device, it has to be transported to the suitable equipments and devices for converting it into usable form for the

consumers. The system used is termed as power take off system, the most popular power take off systems are: hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine, and linear electrical generator.

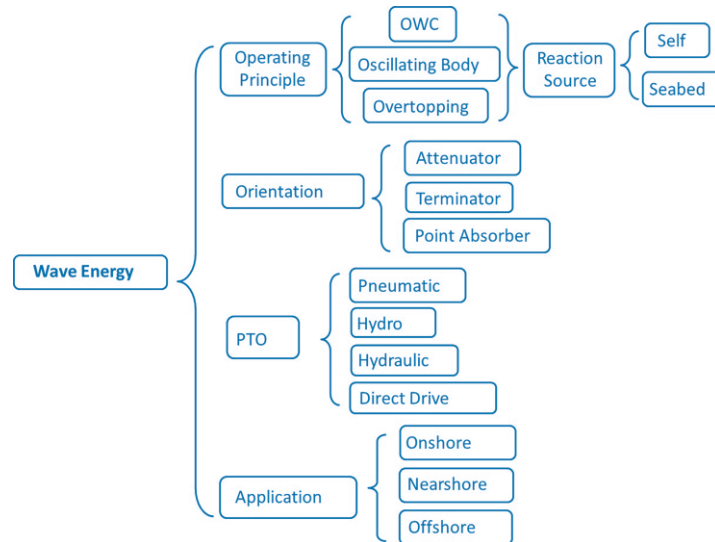


Fig.3. Summary of typical classification of wave energy converters [http://www.irena.org/.../Publications/IRENA Ocean Energy report 2014.pdf](http://www.irena.org/.../Publications/IRENA_Ocean_Energy_report_2014.pdf)

IV. DEPLOYMENT OF WAVE TECHNOLOGY AT OFFSHORE, ONSHORE AND NEARSHORE

For energy conversion, wave power can be captured at different locations viz. onshore, near shore and offshore.

4.1 Offshore Technologies: Offshore Deployment of Devices

4.1.1 Point Observer Devices:

- The 'AquaBuOY' : There were two technologies prevailing in Sweden, the IPS offshore wave energy converter OWEC and the Hose pump. M/s Finavera Renewables of Ireland in their AquaBuOY point absorber have taken care of all the aspects of both the previous technologies of Sweden. The device comprises a slack-moored float (buoy) and a submerged vertical tube, which is open to sea at both its top and bottom. Incident waves cause the device to heave up and down creating a damping force that acts on a piston attached to two hose pumps, which contract and expand to provide a pumping effect. The hose pumps and separate water masses contained within them react against the heaving motion.[6]
- The FO3 has 21 point absorbers mounted in vertical hydraulic cylinders which work in both directions. The vertical movements of the floating point absorbers will be transformed to hydraulic pressure. The hydraulic pressure is used to generate power by generators and numerical calculations . [6]
- The PowerBuoy is a free-floating point absorber wave energy converter that is loosely moored to the seabed; the buoy's float moves up and down on the central spar as the waves pass. This mechanical movement drives a hydraulic pump that forces hydraulic fluid through a rotary motor connected to an electrical generator.[6]

The lead organization M/s Ocean Power Technologies have mentioned in their quarterly report in January 2014 that they have continuous focus on Autonomous PowerBuoy.




- The SPERBUY
 SPERBUY, developed and patented by Embley Energy provides large-scale energy generation at a competitive cost as they claim. The device is a floating buoy Oscillating Water Column (OWC) device consisting of a buoyant structure with a submerged & enclosed column. Housed above the OWC on top of the buoy is all the plant, turbines, generators and associated system facilities. The principle of operation is similar to that of fixed OWC's designed for shoreline and fixed installations. Except that
 - The device is capable of deployment in deep water to maximize greatest energy source and,
 - The entire body floats and maintains optimum hydrodynamic interactions for the prevailing and changing wave spectrum producing high energy capture at minimal cost.

Deployment procedure of the device follows the sequence of installing anchors, laying of farm to shore cables, deploying the device, laying of interconnecting cables and commissioning. The present device is focused on the farm size of 10 devices with inter device spacing 350 meters. The farm size of 1000 devices will require 10 to 15 square kilometers area depending upon the depth of the water. [9]

- e) Wavebob is a freely floating axi-symmetric point absorber capable of resonating across any pre-determined range of wave frequencies and band widths. It may then be tuned to the prevailing wave climate using a proprietary system to change the device's natural resonance frequencies without changing draught. This may be set seasonally or much more frequently as may be justified economically. The instantaneous response of the Wavebob is adjusted rapidly and in real time (during each wave) via the hydraulic PTO by an on-board autonomous control system so that useful power output is maximized.[6]

Wavebob Ltd., an Irish maker of marine energy technology, has been liquidated in the march 2013 after failing to raise money and find a strategic partner to fund its continued development in the past two years. No further detail about their technology is available now. [10]

Table 1: Summary of offshore point absorber technology deployment by different country world wide


Sr. No.	Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
a	AquaBuOY, Finavera Renewables, finavera.com/en/wave , Ireland	Offshore; Point Absorber Integrates 2 technologies originally from Sweden (IPS Buoy and Hose pump)	
b	FO3 Fobox AS http://www.fobox.no/ Norway	Offshore; Point Observer	
c	PowerBuoy, Ocean Power Technologies Inc.(OPT), www.oceanpowertechnologies.com/ , USA	Offshore; Point Absorber	
d	SPERBOY Embley Energy www.sperboy.com UK (Cornwall)	Offshore; Point Absorber	
e	Wavebob Wavebob Ltd. www.wavebob.com Ireland	Offshore; Point Absorber	

4.1.2 Submerged Pressure Differential Devices:

- a) The AWS (Archimedes Wave Swing) consists of a large air-filled cylinder which is submerged beneath the waves. As a wave crest approaches, the water pressure on the top of the cylinder increases and the upper part or 'floater' compresses the air within the cylinder to balance the pressures. The reverse happens as the wave trough passes and the cylinder expands. The relative movement between the floater and the fixed lower part or basement is converted directly to electricity by means of an innovative hydraulic system; in the pilot plant in Portugal, 2004, a linear generator was successfully tested. Variable frequency output is converted to utility grade power using an IGBT converter.[6]

Table 2: Summary offshore Submerged Pressure Differential technology deployment

Device	Name,	Lead Organization ,	Website,	Technology Type	Technology Deployment site
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Country		photo
AWS (Archimedes Wave Swing) AWS Ocean Energy Ltd (invented and developed towards pilot plant by Teamwork Technology) www.awsocan.com UK (Scotland) (originally Netherlands)	Offshore; Submerged Pressure differential	

4.1.3 Attenuator:

- a) The Pelamis Wave Energy Converter is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors. The hydraulic motors drive electrical generators to produce electricity. The Pelamis is designed to be flexibly moored in waters approximately 50-70m in depth. [6]

Table 3: Summary of offshore Attenuator technology deployment


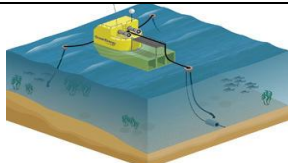
Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Pelamis Pelamis Wave Power Ltd www.pelamiswave.com UK (Scotland)	Offshore; Attenuator	

Fig.29.Pelamis

4.1.4 Oscillating Water Column:

The OE Buoy is an oscillating water column device, where the air in the chamber is pumped out and drawn in through the turbine duct by the movement of the water free surface within the device. Motions of the hull enhance the relative surface movement and increase the air flow. The power take-off system is an air turbine which converts the flowing air into rotational energy which drives the generator. All of the power take-off is above the waterline and not in direct contact with the seawater. [6]


Table 4: Summary of offshore Oscillating Water Column technology deployment

Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
OE Buoy (Ocean Energy Buoy) Ocean Energy Ltd. www.oceanenergy.ie Ireland	Offshore; Oscillating water column	

4.1.5 Overtopping device:

The Wave Dragon is a slack-moored, overtopping wave energy converter. Two curved arms focus waves onto a central ramp which the waves travel up and 'overtop' into a reservoir. At the bottom of the reservoir is a set of low-head hydro turbines, through which the collected water flows back out to sea. The reservoir has a smoothing effect on the water flow, and the turbines are coupled directly to variable speed generators. Since the head of water in the reservoir accounts for the energy, the concept is similar to a hydroelectric power plant. [6]

Table 5: Summary of offshore Overtopping device technology deployment


Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Wave Dragon Wave Dragon Aps www.wavedragon.net Denmark	Offshore; Overtopping device	

4.2 Onshore Technologies: Onshore Deployment of Devices

4.2.1 Oscillating Water Column:

- a) The LIMPET OWC is a 250kW onshore oscillating water column device, which was developed as a follow-up for the successful Islay plant at the same location. LIMPET was installed between 1998 and 2000 on the Isle of Islay off the west coast of Scotland. It was initially designed for $2 \times 250\text{kW} = 500\text{kW}$. An interesting lesson learnt for OWC operation in general was that in the beginning of operation, the developers were obliged to introduce a sound muffler, as nearby population complained about the noise.[6]

Table 6: Summary of Onshore Oscillating Water Column technology deployment


Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
LIMPET OWC Wavegen Ltd (owned by Voith Siemens,) www.wavegen.co.uk UK	Onshore; Oscillating water column	

4.3 Near-shore Technologies: Near-shore Deployment of Devices

4.3.1 Point Observer

- a) Wave Star Energy's wave machine is a so-called multi point absorber. That means a machine equipped with a number of floats which are moved by the waves to activate cylinders, which press oil into a common transmission system, the pressure of which drives a hydraulic motor. The motor, in turn, drives the generator of the wave machine. In the event of a storm the floats are lifted to a safe position – on the large-scale machine they will hang 20 meters above the surface. A sensor on the seabed ahead of the machine measures the waves and ensures that the storm security system is automatically activated. The machine can be remotely controlled via the Internet (VPN connection).[6]

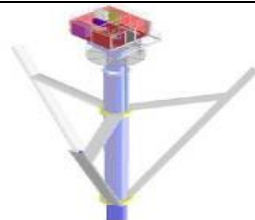
Table 7: Summary of near shore point absorber technology deployment

Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Wave Star Wave Star Energy www.wavestarenergy.dk Den mark	Near-shore; multi- Point Absorber	

4.3.2 Submerged Pressure Differential

- a) The Wave Rotor captures wave energy from the circulating water particles in the waves and also tidal currents. The circular currents can directly drive the rotor. The waves turn the rotor with sufficient torque for power to be taken off by a conventional generator coupled via a gearbox to the vertical shaft. This requires the waves to exert forces on the blades and the combination of blades shown (both a Darrieus arrangement and blades perpendicular to the shaft) is intended to optimize these forces. The power is transferred to the rotating shaft directly, albeit at slow speed. Two types of rotors are combined: a Darrieus rotor and a Wells rotor. These are respectively omni - and bi-directional rotors, which can operate in currents of changing directions.[6]




Table 8: Summary of near shore Submerged Pressure Differential technology deployment

Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Waverotor Ecofys. www.ecofys.nl Den mark	Nearshore: Submerged Pressure Differential	

4.3.3 Oscillating Water Column

- a) The Energetech OWC device is near-shore bottom-standing oscillating water column rated 500 kW, developed by the Australian start-up company Energetech. The device has two particularities, namely the especially developed Denniss-Ault turbine and the structure that was made entirely of steel, including the parabolic-shaped steel arms forming a harbor for tuning the device better to incident waves. The device was placed on the sea bottom in front of the breakwater of Port Kembla, Eastern Australia, where a reef prevents high extreme loads due to wave impacts. The company was re-named into Oxeanlinx and is presently working on the development of an offshore version, apparently resembling a tension-leg platform principle. [6]

Table 9: Summary of near shore Oscillating Water Column technology deployment by different country worldwide

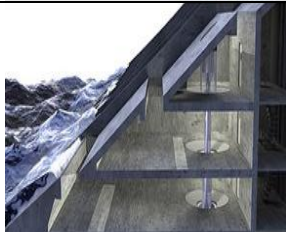
Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Energetech OWC Oceanlinx www.oceanlinx.com/ Australia	Coastal/near shore Oscillating Water Column	
Mutriku Breakwater MOWC EVE (Ente Vasco de la Energia) www.fedarene.org/publications/Projects/NEREIDA/NEREIDA-1st-e-Newsletter/Nereida-e-Newsletter1.htm Spain (Bask Country)	Coastal/near shore Multi Oscillating Water Column	
Pico OWC Wave Energy Centre www.pico-owc.net Portugal (Azores)	Coastal Oscillating Water Column	

- b) The MOWC project wants to demonstrate the successful incorporation of OWC technology with Wells turbine power take-off into a newly constructed rubble mound breakwater in Mutriku, in the North coast of Spain. [6]
- c) The PICO OWC is a European Pilot Plant based in the oscillating water column principle. The Pico Plant is located in the Pico Island, Azores, Portugal. Its construction was concluded in 1999. This plant consists of a hollow reinforced concrete structure – a pneumatic chamber - above the water free surface that communicates with the sea and the incident waves by a submerged opening in its front wall, and with the atmosphere by a fiber duct with a Wells turbine. Up-and down- movement of water column inside chamber makes air flow to and from the atmosphere. The turbine is symmetric and is driven indifferently in which direction the air flows. [6]

4.3.4 Overtopping Device

- a) The SSG (sea Slot-cone Generator) is an overtopping wave energy converter. It consists of three reservoirs on top of each other where the overtopping water from the incoming waves is temporarily stored at a higher level than the sea water level. The potential power of the water in the reservoirs is then transformed in electricity by low-head turbines.[6]

Table 10: Summary of near shore Overtopping Device technology deployment

Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
SSG Waveenergy AS www.waveenergy.no Norway	Coastal or near- shore Overtopping Device	

4.3.5 Oscillating Wave Surge Converter:

- a) Oyster is a near-shore bottom-mounted device designed to interact efficiently with the dominant surge forces in shallow water waves. The principle consists of an oscillating module fixed to the seabed in depths of 12m at the mean water level. The module extracts the energy from passing waves and transmits it as seawater hydraulic power to a hydro-electric power conversion unit, located onshore. [6]

Table 11: Summary of near shore Oscillating Wave Surge Converter technology deployment by different country world wide

Device Name, Lead Organization , Website, Country	Technology Type	Technology Deployment site photo
Oyster Aquamarine . www.aquamarinepower.com Northern Ireland	Near shore; Oscillating Wave Surge Converter	
Waveroller AW Energy Oy. www.aw-energy.com Finland	Near shore; Oscillating Wave Surge Converter	

- b) A WaveRoller device is a plate anchored on the sea bottom by its lower part. The back and forth movement of bottom waves moves the plate, and the kinetic energy produced is collected by a piston pump. This energy can be converted to electricity either by a generator linked to the WaveRoller unit, or by a closed hydraulic system in combination with a generator/hydraulic motor system. A WaveRoller plant is composed by a number of production modules. Each production module consists of 3 wave elements. [6]

V. CONCLUSION

It had become one of the most challenging technological problems of the beginning of the 21st century to extract of wave energy. Wave power energy is abundant in nature with a vast expansion of oceans around the world. Wave power is more predictable than wind or solar energy, although it is in general less predictable than tidal energy. It has higher energetic density allowing in this way extraction of more energy in smaller areas.

The technology developed over the years is new and not much experience is available. This technology can be differentiated from the point of view of principle employed in the devices developed or on the basis of location where wind power energy is being harnessed. However the many of the technologies are named after their developers like Pelamis technology or AquaBuOy or PowerBuOY Technology. The purpose of the above literature was to develop an understanding about the various technologies used in the field of wave power technology with the help of insight of principles employed in devices used in harnessing wind power energy and with the examples of deployment of devices, incorporated by leading developers, onshore, near-shore and offshore. The technology is still under development and the emphasis is to develop sustainable technology with minimization of impact on environment and ecological balance, at the time to improve the factor of extracted power from wave having enormous power potential.

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