Recent Trends in Point Absorber Wave Energy Converters

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ABSTRACT
Ocean energy still remains as unexplored massive source of renewable energy. Survivability of the structures is the major impediment in harnessing this type of energy. Amongst ocean energy conversion, wave energy is a viable option since the wave energy converters are not detrimental to aquatic life. Point absorber wave energy converters have better structural survivability compared to other wave energy converters due to their small size relative to the wavelength of the incident waves. A brief survey of the commercial deployment of the point absorber wave energy converters is presented in this paper. Point absorbers continue to be viable option for wave energy conversion.

Keywords:
buoy, ocean waves, point absorbers, renewable energy, wave energy converter, wave energy

1. INTRODUCTION

Demand for energy has increased day by day and at the same time, fossil fuels sources are being increasingly depleted in nature. Hence, there is a huge concern on looking for alternative energy sources. The rapid industrialization has resulted in the increased emission of carbon monoxide and other hazardous gases. Hence it has become pertinent to study the various renewable resources in the field of electricity generation. Due to global industrialization, the world has severely increased global warming phenomena such as rising CO_2 levels which have necessitated more focus on extracting electricity from renewable sources. Among renewable energy, ocean wave energy is one of the promising forms of energy with an estimated potential of about 2TW of the world's total power generation [1].

Ocean Waves are created mainly sue to the oceanic winds and the air-water interactions on the sea surface. Wind blowing over the surface of the ocean push the water due to the geological effects and may travel thousands of miles before striking the land. The size of the waves vary from small ripples to tsunamis and create large energy potential out of which a feasible portion can be converted to useful electrical energy. Solar energy is the main source and cause of wave energy, as the sun's thermal radiation increases the air temperature which leads to generating winds and finally creates propagating waves along the surface of the ocean [2].

The largest quantity of wave energy received is by Asia and Australasian region as shown in Fig.1[3] with South and North America also receiving fair amount. Wave energy is also significantly available at western seaboard Western and Northern Europe performs well given its relatively small size. Further Mediterranean Sea, Atlantic Archipelagos and Central America have lesser wave energy potential compared to other regions. The total world's wave energy potential is of 29,500 TWh/yr.

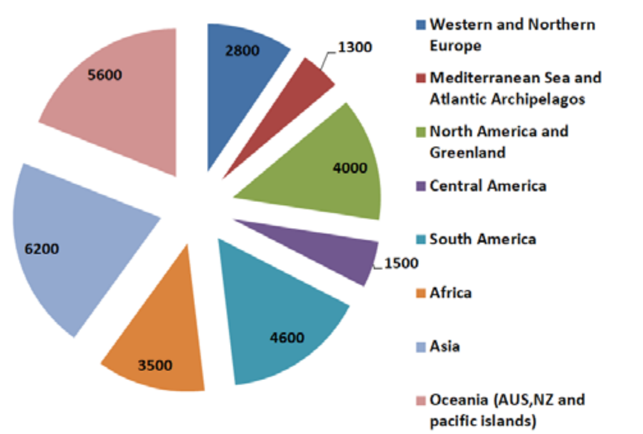

Fig1. Distribution of total world's wave energy potential of 29,500 TWh/yr[3].

2. BENEFITS

Compared to other modes of energy generation, ocean waves as a source of renewable energy offers significant advantages.

Among all renewable energy sources, ocean waves provide the highest energy density [4]. Waves are generated in the ocean by temperature variation in the atmosphere due to the solar radiation. Nearly 0.1- 0.3kW/m^2 of solar intensity in horizontal surface is converted to an average power flow intensity of 2 - 3 kW/m^2 of a vertical plane perpendicular to the wave propagation slightly below the surface of water [5]. Negative environmental impact is limited in use. Thorpe [6] explains the potential impact and presents an estimation of the life cycle emissions of a typical near shore device. In general, it is noted that lowest potential impact in offshore devices.

Waves are active 24 hours a day, 365 days a year. With minute loss in energy, waves can travel large distances. The wind with high velocity carries the waves to large distance [4]. It is observed that wave power devices can generate power up to 90 % of the time, when compared to about 20–30 % for solar and wind power devices [7, 8].

3. CHALLENGES

The harnessing of Ocean energy is significantly challenging mainly due to the issues that needs to be overcome that would result in enhanced performance of wave power devices and would make wave energy commercially competitive in the global energy market. A major challenge is to extract energy from oscillatory, random and low frequency waves and convert extracted energy into useful electrical energy [1]. As the wave height and period randomly vary , the respective power levels also vary in random. Hence, it is challenging to convert variable input to smooth electrical energy.

In offshore locations, wave energy converters align themselves according to the direction of waves that are random in nature. The challenge of effective design of energy extraction devices to withstand extreme wave conditions. The speed of offshore waves is around 30–70kW/m [9].

The extreme saline nature of sea water makes it pertinent to have corrosion resistant coating for the devices that are employed under operating conditions. This results in higher operating costs [4][10].The ecosystem is disrupted during the construction of powerhouse. This affects the fish and also the fishermen whose livelihood depends on fishing.

4. TYPES OF OCEAN WAVE ENERGY CONVERTERS

Ocean can be considered as a storage house of various forms of energy such as heat stored from the solar radiation, energy from wind and surface water, energy from water currents, energy from biomass, energy from difference in salt concentrations and energy stored in the form of uranium resources to name a few. The primary classifications of available and know ocean energy is based on how they can be converted to electrical energy, the most useable energy format for operations as given in Table 1 below. Nuclear resources definitely have the highest potential but owing to the cost of extraction of these resources and subsequent energy extraction in controlled fission reactors. Geothermal energy is the next big bet but is location specific and not abundant. Of these, Ocean thermal energy converters (OTECs) and ocean wave energy converters are reasonably available in most of the oceanic regions and feasible. Of this the OTECs also have significant energy losses due to the inherent nature of heat as a highly susceptible form of energy to expend. Thus, more research is now concentrated on harnessing Ocean wave energy. Also, if one sums up the coastal line of all the landmass regions of tour planet, it is about 5000 kilometers owing to OWEC potential of approximately 5000GW. Only a small percentage of this energy potential can be harnessed owing to geographical and other region specific environmental conditions as well as the premature state of wave energy products.

Table 1 Classification of Ocean energy converters [11]

No.	Ocean energy	Basic principle of energy transduction	Potential (GW)
1	Ocean thermal energy conversion (OTEC)	Temperature gradient to electric energy	10,000
2	Ocean wave energy conversion(OWEC)	Wave kinetic energy to electric energy	5,000
3	Tidal energy conversion(TEC)	Potential difference between high tides and low tides used to extract energy	200
4	Ocean current energy conversion(OCEC)	Kinetic energy of the ocean currents converted to electric energy	50
5	Ocean salinity gradient energy conversion(OSGEC)	Electric potential between saline water and fresh water separated by a semipermeable membrane	3,540
6	Offshore geothermal energy conversion(OGEC)	Thermal energy from the Geothermal fluid to electrical energy	30,000
7	Ocean bio-mass resources	Ocean biomass as fuel is converted to useful forms of energy including electrical energy.	800
8	Ocean nuclear energy conversion	Uranium resources in ocean used in nuclear power plants.	80,000
Total Ocean energy potential of the world			**129,000**

Due to significant research and development of new prototypes, classification of wave energy converters (WECs) remains vague. According to their location relative to the land, they can be classified as off-shore, near-shore and on-shore types[12][13]. According to their operation on the sea level, they can be classified as emerged, submerged and semi-submerged. According to the structural configuration, they can be classified as freely-floating with the mooring system anchored to the sea bed or bottom-standing. One prominent classification that makes sense is distinguishing the OWECs by the method of energy capture[12][13] as indicated in the Table 2 below. This classification is widely used in the reported research and developed products.

Table 2 Classification of OWECs based on Energy capture [12]

No.	OWEC type	Principle of energy capture
1	Oscillating water column	The air turbine is run by an air column pushed by water column that is pushed up during the incident wave tide.
2	Archimedes effect	Relative motion between the air filled buoy and the fixed base that is moored to the seabed.
3	Floating buoy with fixed reference	Float moves with respect to a fixed reference, usually the point that is fixed on the seabed.
4	Floating buoy with moving reference	Float moves with respect to a moving basement that is not anchored.
5	Overtopping	Shore side consisting of turbine that is run by the tide hitting the shore.
6	Impact	Submerged oscillating WEC that oscillates during impact force.

Another classification based on current deployment literature is class A to class I classifications from European Marine Energy Centre [13] as per the table 3.

4. ABOUT POINT ABSORBERS

A point absorber is a buoyant WEC with single or multi-degree of freedom body oscillating relative to a fixed member[14]. The build of the point absorbers are small compared to the average wavelength as decided by the analysis of the wave characteristics. Point absorbers are submerged WECs designed to convert the surface waves to generate electricity. Point absorbers are built custom to their locational wave characteristics and hence a detailed investigation of the wave parameters such as wave frequency, wave length, maximum wave displacement and wave period to name a few. Also, in general, their size is designed to be about 0.05 to0.1 times the most common wavelength as per annual wave data characteristics. This is followed by wave structure interaction analysis to determine the structural stability and natural frequency of the proposed point absorber system. It has been found that maximum power is achieved when the natural frequency of the point absorber is in resonance with the incident wave frequency. Hence, point absorbers are designed after determining the most commonly occurring incident wave frequencies. Another important design consideration is the structural survivability aspect of the point absorber which is achieved by fluid structure interaction models that achieve greater stabilities of the pitch, yaw and surge forces of the prevalent wave conditions. Very often, the structural survivability is achieved at the expense of energy conversion efficiency. The other design factors to be considered include electro-mechanical transduction mechanism, design for safety and reliability, build costs, life cycle costs and costs of maintenance.

Table 2 Classification of OWECs based on Energy capture [13]

Class	OWEC type	Deployment %
A	Attenuator	23%
B	Point absorber	40%
C	Oscillating wave surge converter	19%
D	Oscillating water column	7%
G	Bulge wave	1%
H	Rotating mass	7%
E	Overstopping/Terminator	
F	Submerged-pressure differrential	3%
I	Others	

One classification of PAWECs is based on their locations-offshore PAWECs, near-shore PAWECS and shore-line PAWECs. The design of Offshore PAWECs needs to be robust in terms of structural survivability where the waves are turbulent but wave energy potential is very high in these regions.

Near shore PAWECs and shore-line PAWECs often witness flow that are relatively laminar compared to offshore and hence more safe but have lesser wave power potential. Another classification is based on the principal direction of wave energy conversion – heaving, pitching and surging out of which the heaving and pitching are most commonly used.

4. RECENT PATENTS IN POINT ABSORBERS

Hagmüller, A.W and Levites-ginsburg, M. J (US 20190063395) proposed an intelligent wave energy converter system that is adaptive to the prevailing sea conditions by sensing the wave parameters and being responsive such that the natural frequency of the WEC system is in resonance with the frequency of the sea waves[15].

Point absorbers using elongated inexpensive light weight buoys with self-orientation capabilities to multi-directional wave forces was proposed by Rohrer,J.W (15/863947)[16].These PAWECs are capable of harvesting energies from both heaves and surges of the existing waves. Another feature of this PAWEC is to submerge completely during severe seas to accommodate survivability conditions.

Thresher, R. et.al,(US20190040839)[17] proposed wave energy converters that can be geometrically reconfigured by employing actuated geometry components to effectively transfer wave energy to the PTO component.

A method of harnessing energy from the heave motion of the incident waves by estimating and computing the heave excitation followed by subsequent application of the controlled force was suggested by Abdelkhalik, O. et al.(US10197040)[18]. The estimation of the heave excitation can be obtained by measuring the surface pressure and position of the buoy whichis more accurate than the measurement of wave elevation.

Gregory, B.[19] suggested a submerged point absorber that lies between the float at the sea surface and the sea bed by means of two special mooring tauts on either side. It is possible to dynamically control the lengths of these tauts either between sea-surface and point absorber or between point absorber and the sea bed in accordance with the wave height at that instant.

A self-powered computing apparatus integrated within the float was suggested by Sheldon-Coulson, G.A (US2018/042023)[20].This device also includes novel features to economically cool the computing circuits using its close proximity of the sea water and oceanic wind waves.

Sidenmark, M. (SE2018/050599)[21] suggested a PTO device of PAWEC which consists of a float and a drive unit. The drive unit comprises a mechanism to convert linear motion of the buoy to convert to rotary motion, rotary input shaft, variable transmission unit and energy storage device. The variable transmission provides adaptive control on storage or retrieval of the stored power and also the force applied from the drive unit to the float.

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Todalshaug, J.H[23] introduced a PAWEC that consists of a float oscillationg relative to a fixed point and a negative spring connects the float to the fixed point. Here, the negative spring helps to apply positive force in the direction of displacement as the float moves away from its mean position.

Yang,Y.(US 15/301823)[24] proposed a wave energy converter that has a special unidirectional rotor consisting of multiple lift type and/or drag type blades and a vertical shaft perpendicular to the incident waves.

4. COMMERCIAL DEVELOPMENTS OF POINT ABSORBERS

Seabased, a Swedish company in collaboration with Swedish agency and Fortum has developed its PAWECs at Sotenas, Ghana, Aland and Islandsberg[25]. In their Waveparks a multitude of PAWECs are connected to the linear generators beneath the sea that convert them into electrical energy and send to subsea switchgears that are connected to the grid.

SINN Power GmBH[26] recently launched its second phase of renewable energies project at Guinea for its client Guinea Gold PLC. SINN Power WECs are arrays of PAWECs that reciprocate up and down in a constrained structure. Each PAWEC reciprocates a rod that acts as driver for the generator unit.

Another WEC concept that uses hydraulic pistons placed on a point absorber was proposed by Ocean Grazer, a dutch startup[27]. The startup is currently planning to develop hybrid offshore energy converters by integration wind and other feasible renewable sources with ocean wave power extraction.

Flansea from Belgium[28] introduced an offshore PAWEC that works based on the bobbing effect of the point absorber buoy on the cable. It was custom designed for deployment in the Southern North sea wave environment.

SDE from Israel [29] developed SDE Waves power plant in 2010, which is based on hydraulic rams connected to the generators are operated by the pumping motion of buoys. One of the SDE waves power generation produced peak power of about 40kWh during its two year operational tenure (2008-2010).

The WaveEL buoy [30] developed by a Swedish company Waves4Power is PAWEC designed for survivability with shorter horizontal dimensions compared to the average wavelength of the incident ocean waves. This buoy has a long vertical tube with a piston connected to the power conversion system. The moors attached to the point absorbers secure them to their location but also allow them for free vertical motion to extract energy.

SeaRaser from Alvin Smith, UK [31] consists of a point absorber float tethered to a piston pump anchored to seabed. The point absorbers generate pressurized water during their oscillations. The pressurized water is sent through pipes to onshore hydraulic generators to generate electricity.

Oceanus2 launched by Seatricity Ltd,UK [32] consists of a gimbal mounted piston pump supported by the buoy with the pump moored to the seabed. The point absorber reciprocates vertically up and down thus driving the pump and developing hydraulic pressure. The pressurized water is either sent to reverse osmosis desalination plant as input raw material or hydraulic turbines for power generation. OE Buoy developed by Ocean Energy, Ireland [33] consists of only a simple moving part and has potential rated capacity of 125 MW.

Other prominent Point absorbers include the AquaBuoY from SSE Renewables [34], Lysekil project from Uppsala University[35], Wavestar Buoy from Wavestar A/S[36],CETO Wave power from Carnegie, Australia [37], Wavebob from Ireland [38], Atmocean from US[39] and PowerBuoy from Ocean Power Technologies, US[40] to name a few.

3. CONCLUSION

It has been observed that there is considerable research and working prototypes being developed across the world to harness wave energy converters. This is due to the massive availability of wave energy that is available and can be utilized for growing energy needs. PAWECs and other wave energy converters are safer options without significantly hampering the aquatic life and the ocean environment. Survivability of the PAWECs is stillan issue that will affect the wave energy extraction process and hence stability needs to be critically addressed in the PAWEC design.

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