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Review of wave energy extraction technologies and current state of the art

Sarmad Iqbal
talentedarther2014@gmail.com
COMSAT University, Islamabad, Pakistan

Muhammad Abubakar
bakarfarooqi619@gmail.com
COMSAT University, Islamabad, Pakistan

ABSTRACT

In renewable technologies, ocean wave energy extraction tech is in the early development phase, especially wave power extraction technology. To extract power from waves, a generator with moving parts is used to change wave energy into mechanical energy. Now floating systems and designs that can take benefit of PE and KE are also developed. The main aim and objective of this research article are to make a complete understanding of ocean wave energy extraction technologies. This article will also tackle the potential and consumption that wave energy. This article will also explain the different energy conversion projects at different levels around the world.

Keywords— *Wave Energy, Renewable Energy, Point Absorber, Attenuator, OWC, Overtopping*

1. INTRODUCTION

For the reduction of greenhouse gas emission and the good future of all countries, a clear renewable will play an important role because of most of the greenhouse gases exit due to non-renewable energy. According to the renewable global status report 2019, fossil fuel use is 79.7%, 2.2% nuclear energy, 7.5% tradition biomass, and 10.6% modern renewable of total world's energy consumption [1]. The difference between fossil fuel use and renewable energy can level in the coming years if the pace of renewable energy growing continues. In 2018, almost 181 GW installed and grew by 8% as compared to the last year. By the end of 2018, the total installed capacity of renewable energy was 2,378 GW [1]. Solar power capacity grew almost 55%, hydropower 11%, and wind power 28%.

In renewable energy technologies, wave energy technology is new and in the initial phase of development. Power extraction from ocean waves is also new tech in the renewable energy world. To create power energy in waves requires a specific environment and this energy is divided into two parts; potential energy and kinetic energy [2]. There is a need for a technology that can capture energy efficiently from ocean waves. The structure should be designed according to the ocean or marine environment that can bear storm, water pressure, etc. To extract power from waves, a generator with moving parts is used to change wave energy into mechanical energy. Now floating systems and designs that can take benefit of PE and KE are also developed [3].

There are different energy extraction options from ocean waves such as ocean thermal energy, waves, salinity gradients, tidal and ocean current, and submarine geothermal energy. The offshore wind industry is a good example of the use of the marine environment for power generation. Ten European countries have installed 12.6 GW, a total of 81 offshore projects [4]. The wave energy extraction sector can lead from the offshore wind energy sector if new technology can able to travel produced energy up to large distances.

Swells and wind seas are two types of waves but swell waves are more important as compared to wind seas for the wave energy converter industry. According to reports and data, the total potential of wave energy in the world is almost 29,500 TWh/yr but due to lower developed tech, only a small part of power is extracted near the hotspots, coastlines, and islands [5].

The different project has been developed in previous years including Pico plat, which is situated in the Azores and its installed capacity is 400kw. This project faced many issues due to a lack of equipment and pant configuration. This plant redesigned in 2005 and 2009reported that the working hours of this project are 265 hours [6]. Most projects are in the early development stage or installed on a small level. These projects are helping to determine the efficiency and survival issues due to electricity generation.

According to statistics, wave energy can provide 188 GW power in Europe up to 2050 and it is almost 10% of Europe's electricity consumption. This can happen only if experts able to develop new tech and operation instruments with passing time. According to the research and development report, future wave technology can lessen operation and installation costs. Installation cost can reduce 18%, power take-off 22%, foundation6%, maintenance 17%, and grid connection up to 5% [7]. For a sustainable renewable marine project, it is necessary to understand the impact of wave technology over the marine ecosystem.

2. WAVE ENERGY POTENTIAL AND CONSUMPTION

Ocean energy is considered a new type of getting energy in renewable energy. The dominant forms of ocean energy are a wave and tidal power but these are still in development or pilot phase. According to theoretical data, ocean energy has the potential of 29,500 Twh/yr but we can draw only a very small part for electricity generation [8].

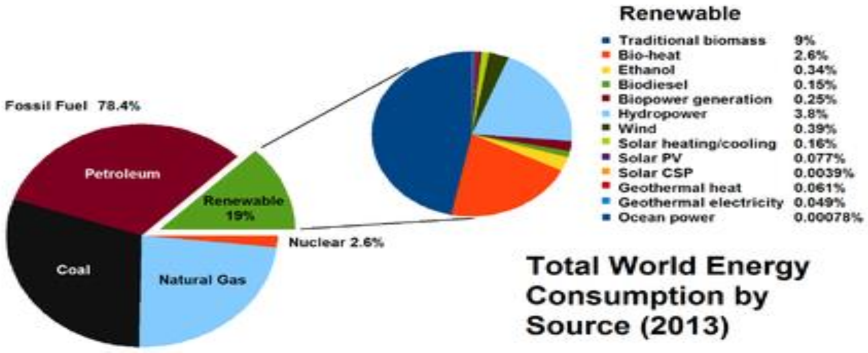

Fig. 1: World energy consumption by a source in 2013; results from [13]

The above fig.1 shows that ocean power is contributing a very small part in world energy consumption. The progress rate of ocean energy technology is very slow as compared to another renewable source due to inappropriate instruments and technical issues.

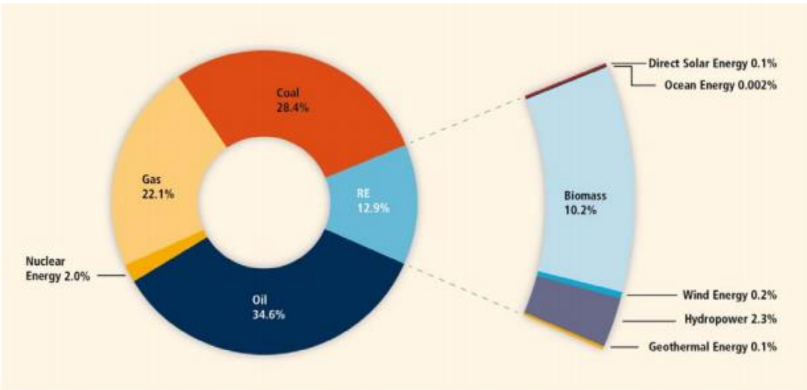

Fig. 2: World energy consumption by a source in 2008; results from [14]

The comparison of both figures shows that there is no progress in ocean energy consumption while the overall consumption of renewable has increased by almost 7% from 12% to 19%. The potential of wave energy in a pace place can measure by different monitoring systems and by satellites orbiting. There can be inaccuracy in data because there can island in the ocean affect the wave speed and intensity [9].

Due to the advancement in computing and technology, now it is easy to predict wave data and easy to develop a model on a local or international scale. Some departments like a national centre for environmental prediction US can predict and give information on local as well as global scale. According to the statistics, North America, Oceania, South America, and Africa have more power density waves as compared to other continents [10].

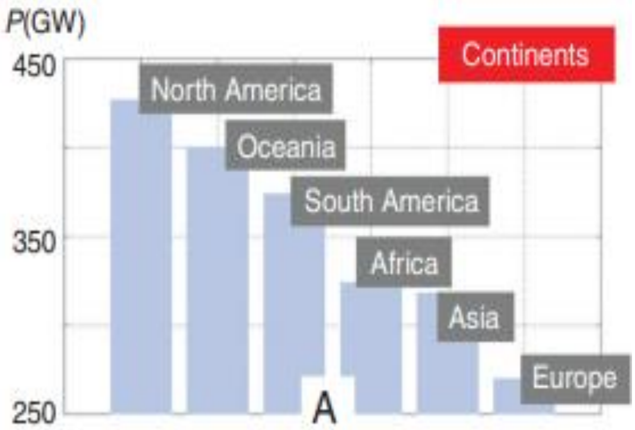

Fig. 3: Total wave power by continents; results from [11]

According to the national oceanic and atmospheric administration's data, North America has high wave power and Europe has less wave power. It is interesting to know that Europe is still leading the world in the ocean energy market and currently producing 66% of total tidal energy and 44% of total wave energy [12]

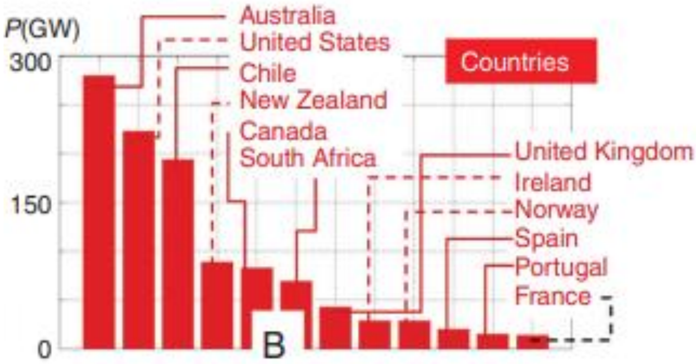

Fig. 4: Total wave power by countries; Results from [11]

In the case of countries, Australia has a more powerful wave in all countries in the United States, Chile, New Zealand, and so on. The main reason for the high power of waves in Australia is because they have long and large coastal areas as compared to other countries.

3. WAVE ENERGY CONVERTERS

It is considered that the first wave energy converter build in France and also patent in 1799. Monsieur Girard proposed direct mechanical action to run and drive heavy machinery including pumps, saw, and mills. After the first patent, thousands of others followed. In the UK, almost 340 patented from 1855-1973. Yoshio Masuda, a Japanese naval commander tested different devices at sea to extract energy for power navigation lights. He is also considered the inventor of different devices such as KAIMEI, which is used in oscillating water column technology [15]. The main innovation in wave energy extraction devices came after 1973 when the world was facing a serious oil crisis.

There are different types of technologies are using to extract energy from waves. The main types of technologies that are using in different projects are; oscillation water column, absorbers, overtopping, and attenuators. Oscillating water columns is the technology or devices that extract wave energy from the oscillations. It consists of a semi-submerged chamber that opens to the sea hollow and keeps the trapped air pocket above the water column. This act forces a column to act like a piston, moves up and down, and continue to keep the air in and out from the chamber [16]. This continuous movement passes a high-velocity air through PTO. PTO is a device that changes airflow into electricity or energy.

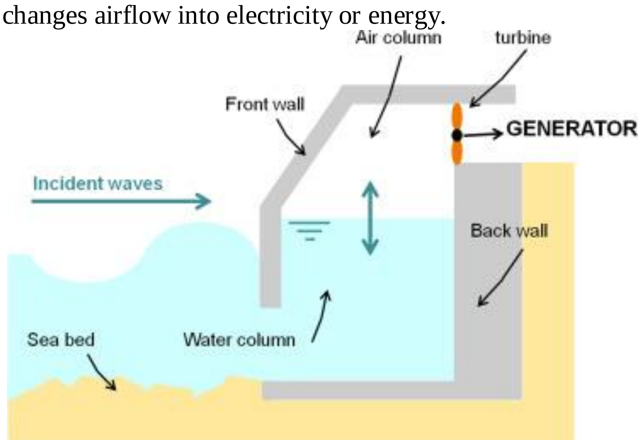

Fig. 5: Oscillating water column model [17]

This technology can be installed on onshore on rocky shores; nearshore up to 10 m and in offshore 40-80 m deep water. Wells turbine is the most commonly used turbine in OWC wave energy extraction. Higher the latitude, above 30 degrees is best for OWC. OWC technology has some negative impacts like noise pollution but can be reduced if placed in deep water. This technology release only 24 grams of carbon dioxide in 25 years life cycle.

Overtopping is a famous technology that is used in wave energy extraction. This technology works like a hydroelectric dam. In this technique, potential energy is water is used to run a turbine and then we get energy [18]. It is something like the waves on the beach that come far and then gets back into the sea. This technology has a large structure and his arms focus to get water from waves of water. The structure of technology is usually a little high from the surface of the water. High waves draw water into structure and then move towards the storage reservoir which is at high elevation as compared to seawater. This high elevation water then moves from the central point where a turbine is installed. This type of technology is usually used near shore but can be used offshore such as Wave dragon [19].

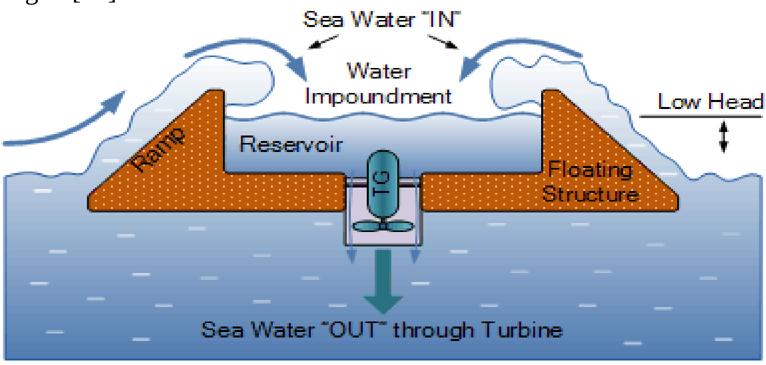

Fig. 6: Model of Overtopping technology-based structure

Two big arms used in the Wave dragon model of overtopping technology that increase the height of waves. This technology developed in 1990 but still there is not much improvement in this area. Denmark has made much improvement in offshore models. This technology has a structure of up to 390m wide and can stand between 1500 to 14000 cubic meters of water. The average installation and build cost is $12 million but has high efficiency that makes it useful and also can run for the long term. Major projects of overtopping based technology wave energy extraction are located in Denmark, Wales, and Portugal. This technology structure can be up to 22,000 tones [21]. Each unit of this technology can produce energy between 4-10 MW. Wave dragon's height can be adjusted according to the requirements. This technology has bad effects on marine life, especially those who live in upper surface water.

	Average wave energy density [kW/m]				
	0,40	24	36	48	60
Width [m]	57	260	300	390	390
Weight [t]	237	22000	33000	54000	54000
Reservoir capacity [m^3]	55	5000	8000	14000	14000
N. of turbines	1+3+6	16	16-20	16-20	16-24
Power production [Gwh/year]	-	12	20	35	43
Generators, rated power [kW]	2,5	250	350-450	460-700	625-940

Fig. 7: Dimensions of WD prototype [21]

This technology can be designed according to the requirements. Size, weight, no. of turbines, width, etc. can set in the designing process. A point absorber is another technology that is used in a wave energy extraction device. This device floats on the surface of seawater and attached with a cable to hold the structure. The point absorber structure can be partially or submerged underwater. Different projects are working in the point absorber technology like CETO and Power buoy. In the CETO project, the structure is point absorber based and completely submerged underwater [22]. This technology uses the high pressure of waves and converts it into electricity.

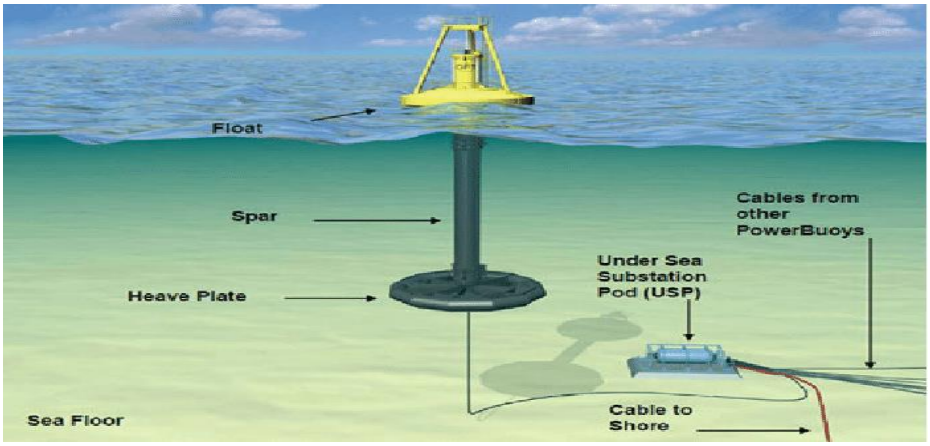

Fig. 8: Point absorber

The best-known point absorber device model is PB150 which is developed by ocean power Technologies Company. This device has a piston-like structure and piston moves with the pressure of waves. The company is developing a new model PB500 which has a capacity of 500KW but this model is still in testing condition. The maximum operational height of the Buoy is 80ft, which installed by ocean power technologies.

As compared to other technologies, this device has more potential to produce power with a small structure. The Buoy size in this device can be up to 6m and can use with a maximum depth of 50m. Like other wave energy Converters, this technology is also in the initial stage and maximum power can generate up to 250KW. The structure of this technology is made up of steel and other

material that is used in shipyards. Hydraulic impulse turbine is used to convert water pressure into electricity. The pump compresses the pump up and down with waves. Electricity is transmitted by the seabed cables to the grid [23].
The estimated life of point absorber is almost 20 years. Most projects of point absorber technology installed in Europe, North America, and Asia pacific. According to experts, North America is the best place for this technology and there are many chances of massive investment in the coming years. Major companies that are working on the improvement of point absorbers are Carnegie Corporation, Wave Bob Ltd, AWS ocean energy Ltd, and Pelamis wave power Ltd.

The attenuator is another type of wave energy converter that is used in wave energy extraction. This structure placed parallel with the direction of a wave and holds this structure with the help of mooring on the seabed. Sea waves make pressure on the turbine then, the device move with the pressure of crest and troughs.

Fig. 9: Attenuator internal parts

This technology is very similar like point absorber. Both technologies parts move with the pressure of waves. The most common type of this technology is Pelamis, designed by the Pelamis power energy company. This device developed in Scotland and its designed capacity is 2.5 MW but still, the company is getting only up to 750 kW. Pelamis is considered the world's first commercial machines but now they have different new versions of this machine. Anaconda is another model of attenuator based technology. The length of this model is up to 200 m and a capacity of 1 MW. The benefit of this technology is that we need fewer power waves to operate the system.

4. MAJOR PROJECTS OF WAVE ENERGY TECHNOLOGIES

LIMPET is a major OWC project in Scotland that has capacity 500 kW with wells turbine of single 2.6 m diameter. This plant was built by Wavegen Ireland Ltd with the partnership of Queen's University Belfast. This project completed in 2001. Mutriku is another big project of OWC based technology that has a capacity of 300 kW. This power is enough for 250 houses. In this project almost, 16 small wells turbine used, provided by Voith Company.

Table 1- Wave energy converters installation (kW) around the world [24]

Country	Planned	Installed	Operational	Total
Canada	0	0	11	11
New Zealand	0	20	0	20
Denmark	39	12	1	52
Italy	0	150	0	150
Mexico	200	0	0	200
Ghana	0	0	450	450
Spain	0	230	296	526
Korea	0	0	665	665
China	0	400	300	700
Portugal	350	0	400	750

Major projects of overtopping technology are Oyster, Wave Roller, TAPCHAN, SSG, and Wave dragon. The projects are fixed as well as floating and also have different capacities. Oscillating bodies like point absorber and attenuator also have some commercial projects like Pelamis, SEAREV AWS, Aqua Buoy, and Wave bob.

Table 1- wave energy converters projects

Technology	System	Projects	Year	Location
Oscillating water column	Fixed + Floating	Pico LIMPET Mutriku	2010 2000 2009	Portugal UK Spain
Overtopping	Fixed + Floating	Wave dragon Wave plane	2003 2013	Denmark Denmark
Point absorber	Fixed + Floating+ submerged	Ada Foah waveform Azura Sotenas	2016 2015 2015	Ghana The U.S.A. Sweden
Attenuator	Floating	Galway bay project Agucadoura	2016 2015	Ireland Portugal

Researchers are working on new technologies or improving existing technologies by changing turbines, control schemes, etc.

5. CONCLUSION

Due to unlimited non-renewable sources in the world, most countries now are looking for renewable energy technologies. The demand for renewable energy increased after the 1970 oil crisis. There are different types of renewable energies and all have enough potential to run the world smoothly. Solar and wind are more developed renewable technologies as compared to others. Wave energy is in the initial stage of development. In this paper, I discussed the wave energy in a different perspective. This paper also discussed the potential and consumption of wave energy. Wave energy has a lot of potentials but to less development, this technology is contributing a little in energy consumption. In this paper, major technologies discussed that are using in the wave energy extraction. The last part of this paper explains the major projects in the world that are based on different technologies.

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