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Wave Energy Convertors (WEC): A Review of the Technology and Power Generation

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Abstract. Wave energy converter (WEC) is being increasingly applied in many countries as major promises resources. These WEC's have been developed to extract energy from shore line out to the deeper waters offshore. The paper discusses the latest development of wave energy convertors. Several topics are addressed: Theoretical and conceptual background, technology related-power take-off, advantages and limitation, power production, main types of WEC and also future prospect.

INTRODUCTION

The winds that blowing over the surface of the sea will produced an energy call waves. These waves will form a different size which all of these size were generated depends on the wind speed, the bathymetry of the seafloor, the distance of the water over the wind blows and its currents. Moreover, kinetic energy which carries from the resultant movement may be harness by the wave energy devices. More than two centuries, the researchers and inventors have proposed many type of different devices for employ these wave power for the benefit of human being. However, after the First World War in the late 1940s the interest for the wave energy utilisation turn out to be faded since petroleum become the most imperative modern source of energy. But, the researchers have started back their interest in entering this research field since the oil crisis happen in 1970s [1]. The global power potential represented by waves that hit all coasts worldwide, has been estimated to be in the order of 2TWh/year (2 terawatt=10^{12}W) [2]. The demands of the world consumption of electricity are around 16 TWh/year. The wave energy alone could supply the world consumption and solve the current issues mainly on depletion of fossil fuel and carbon emission. If wave energy is harvested on open oceans, energy that is otherwise lost in friction and wave breaking may be utilised. Then the global wave-power input is estimated to be one order of magnitude larger (~10^{13}W), a quantity that is comparable with the world's present power consumption. Because wave energy converter is still young or new compared to wind energy or solar energy, they still in prototype progress. More than one thousands patents had been registered by 1980. In 2008, the first commercial ocean energy devices named SeaGen and Pelamis being installed in UK and Portugal [2]. Although the wave energy has important potential, this energy are not being utilised so far on a significant scale.

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THEORETICAL AND CONCEPTUAL BACKGROUND

Basically waves are caused by four main reason as which the gravitational effect from the sun and moon, earthquake, wind blowing at the surface of the open water, and the atmospheric pressure changes. The most relevant waves for the wave energy convertors are created by the wind. In real conditions, wave is an irregular with low-frequency energy sources. This means waves are a powerful source of energy, but are difficult to harness and convert into electricity in large quantities.

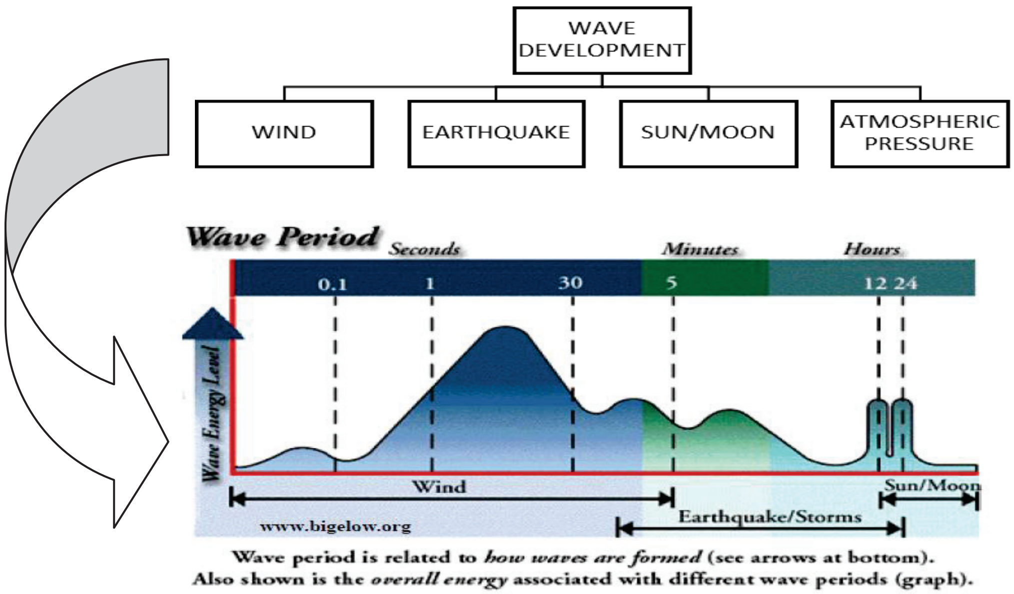


FIGURE 1. Wave Development Sources [3]

There are several sources of wave development. The most significant sources are wind, which the wave energy and wave height can achieve its maximum in short period time. The comparison between wave to solar and wind energy is, just below the ocean's surface, the wave energy flow, in time-average, is typically five times denser than the wind energy flow 20 metre above the sea surface, and 10 to 30 times denser than solar energy flow.

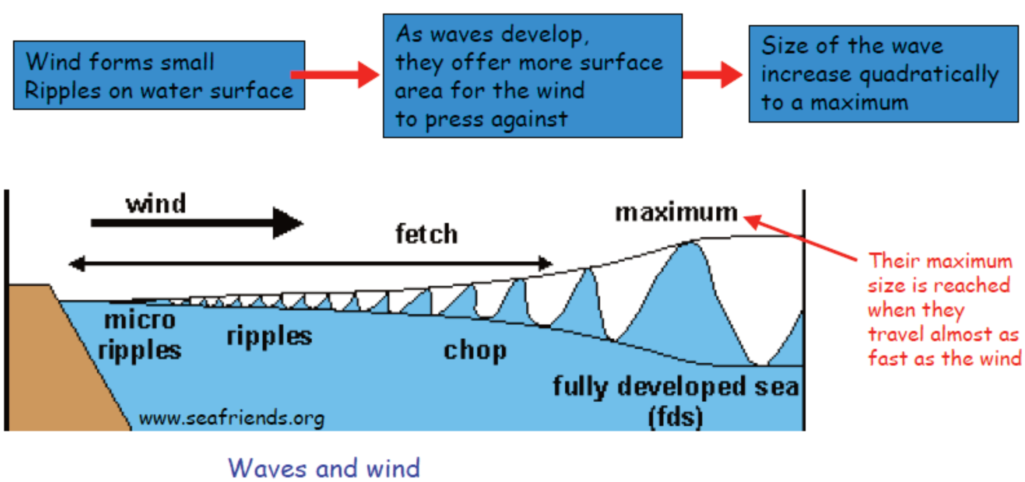
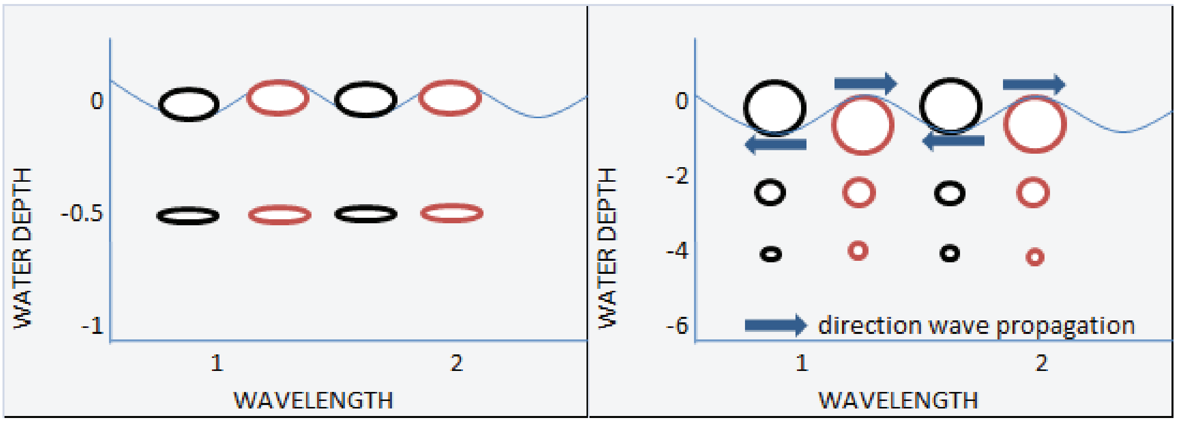


FIGURE 2. Wave Development Sources [4]

Basically, wind energy is created by natural conversion of part of solar energy. By heating air, the sun creates winds. Wind blowing along the water's surface creates waves, as in Fig. 2. The blowing wind will form small ripples on water surface along its path. Soon, as waves develop, they offer more surface area for the wind to press against known as chop. Eventually, the size of the waves increases quadratically to a maximum size, when the waves travel almost as fast as the wind.



(a) (b)

FIGURE 3. (a)Wave Particle Motion for Deep Water (RHS) and (b) Shallow Water (LHS)

The Fig. 3 above illustrates particle movement in deep (RHS) and shallow water (LHS) waves. The diagrams use vertical exaggeration for clarity. In deep water, wave particles move in circles, in shallow water waves particles move in very flat ellipses. Particle movement decreases rapidly (exponentially) with depth in deep water waves but remains essentially the same over the entire water depth in shallow water waves, due to pressure acting on it, This pressure is roughly equal to 1 atmosphere for every 10 meters below the surface. A body at open sea may move in six different directions simultaneously which are sway, surge, roll, yaw, heave, and pitch.

In real condition, conversion of wave energy into usable energy is extremely complex because of the irregular wave produce the diffraction and radiation that result to hydrodynamic changes. The generator known as power take-off must able to capture and convert the wave energy and also cope with the electrical utility grid line which generally used 50 or 60 Hz [5]. The design of energy convertors device requires reliable estimates of the available power and the seasonal variations [6]. All of the information above are basic to design the wave energy convertors, in line with the technological aspects, political issues, and economy. The types of energy convertors may come in fixed, floating, and submerged design and continue to improve their performance in harvesting the potential wave energy.

IMPORTANCE AND CHALLENGE

Generating the renewable energy becomes the high priority at national level in the energy policies. However the WEC/RE must meet the energy demand [7]. Today shows that the WEC are still at early stage of development. Besides, the WEC need to consider avoidance shipping and other sea user, military area of importance, and marine archaeological sites. Furthermore, the pipeline and underwater cables further restricted wave power establishment and may interfere with recreation places such as beach [8]. On the other hand, from some studies showing that the most potential wave energy areas are between 40^o and 60^o in both hemispheres, where at this location stated average power around 120 kW/m in South Hemisphere and 90 kW/m in North Hemisphere. This area is located far from the land and overall depth 50-60 m [6][9].

In addition, for two-dimensional wave energy devices case, only half of the incident wave energy can be absorb [10] and some of the wave energy is lost through viscous dissipation in the sea water, friction and heat loss is the system especially in power conversion devices and during delivery to shore. In addition, the reliability of the WEC and other RE often questioned because it is seasonal ie monsoon, wave and tide, and depends on many uncertainties. This will lead to fluctuation on current grid system. On top of that, some studies shows insufficient information among the reason on the market failure particularly on the government, public and consumer along their willingness-to- pay for the sustainable of the project [11] because of the enormous initial cost for construction, installation, and maintenance.

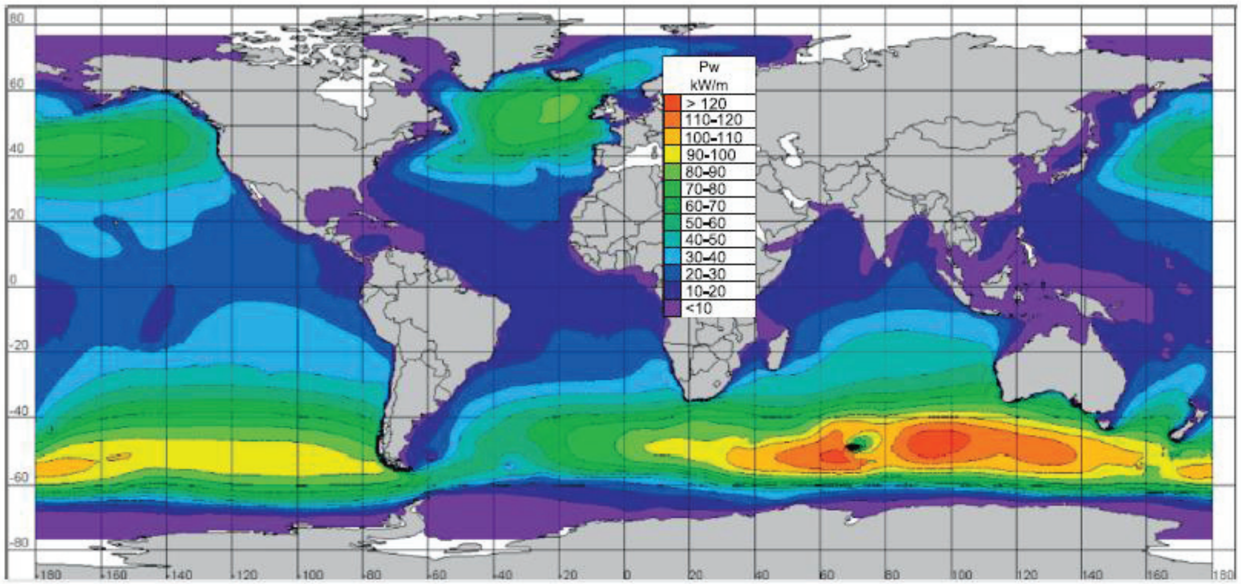


FIGURE 4. Annually Estimation of Global Mean Power Wave in 10 Years Period (kW/m) [9]

These major considerations create the barriers of the WEC development, and can be divided into 4 main categories which are policies, market and economic, knowledge and technology, and environment and social.

POTENTIAL, TARGET AND FUTURE PROSPECT

Many research findings noted that the wave energy are one of the most promising energy resources [2][12][13]. At European, 20 % of the overall from RE are targeted by 2020 [7][14]. In a long term, wave power along the European coast estimated to be able to cover all the Western European electricity demand [14]. Growth and success in a series of prototypes promote spread the research and development to the other countries including Brazil, China, Russia, India, South Africa and some in the Asian region. WEC have a high potential, nevertheless the technologies of WEC are left far behind compare to the other RE. This due to barriers in policies, market and economic, knowledge and technology, and environment and social that will discuss in details.

At present the mitigation of potential generally introduce the future perspective which determine and analyse to close the gap in the WEC. Figure 5 shows the bottom up process, which the market potential forecast show a good prospect in WEC based on survey and research the in the last decade. However the other potential shows a long way to go. The process still continuing to grow and some actions are taken to overcome the barriers.

World Energy Outlook 2007 discussed the future trend projection on energy policies [15]. Historically, the RE based on wave are not popular compared to the wind, solar and others, but in 2001 the development of wave energy evolve on assessment and survey mainly on the European Union. This development important in tandem with the development of science and technology, thus the framework of the study has been revised and undertaken of national expert, lead to analysis of renewable energy's evolution up to 2020', FORRES 2020. From here, it was extend to the several countries including Brazil, China, Russia, India and South Africa for a long term potential forecast model, WorldRES [16]. In order to understand the future prospect, the potential may be studied and can classify into several points as shown in Fig. 6.

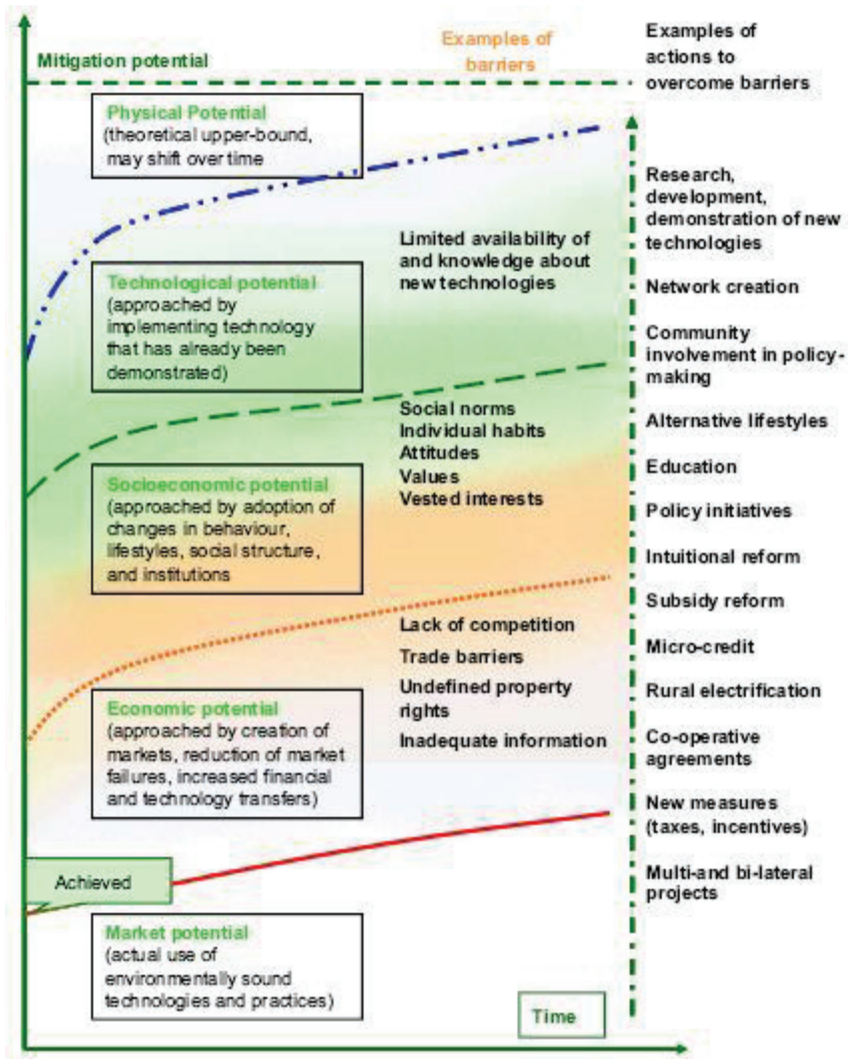


FIGURE 5. Mitigation of Potential Barriers [11]

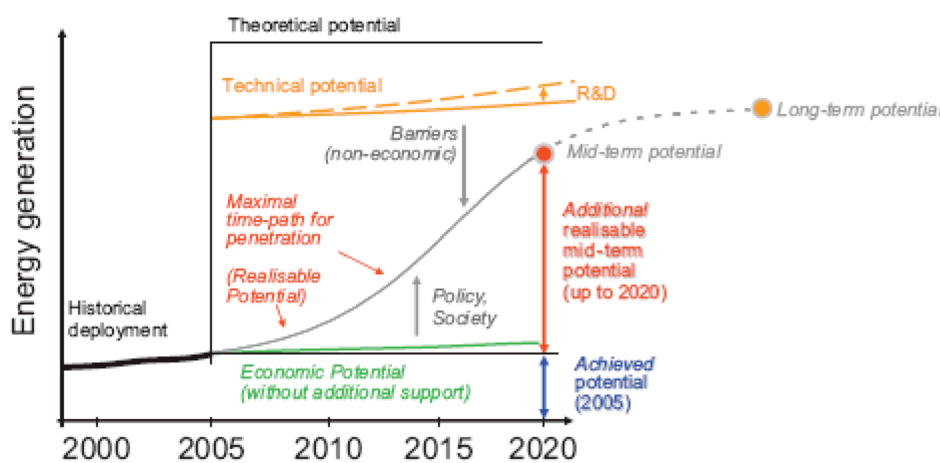


FIGURE 6. Definition of Potentials in Renewable Energy [16]

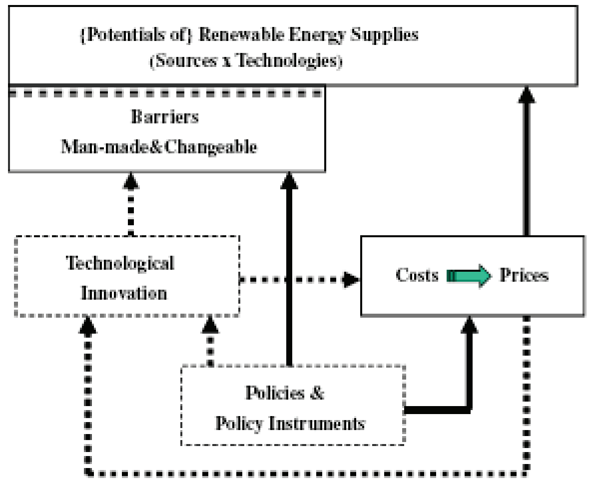


FIGURE 7. Interconnection Between Variable That Affecting Renewable Energy (RE) [11]

The model in Fig. 6 shows the mid-term potential, up to 2020, based on the IEA 2007 [17]. The potentials can be breakdown into theoretical potential, technical potential, realisable potential, mid-term and long term potential. Theoretical potential generally describe the physical parameters on the specific region where it shows the upper limit that can be produced based on scientific knowledge. Technical potential is a dynamic context involved the technical aspect that need to take into account such as the efficiency, technical limitation and technical boundary conditions. This however may improved with increasing in R&D. Realisable potential represent the all existing barriers that may occur for instance markets growth, economic, policy and planning. This term is also very dynamic and always changing. Mid-term and long-term potentials are the potential that can be achieved, influenced by the factor above. In Fig. 7, shows the importance of interconnection that may affect the renewable energy supplies. Policies are main key player that supporting the technological potential and perhaps the development of the realisable potential, particularly in market and economic [11].

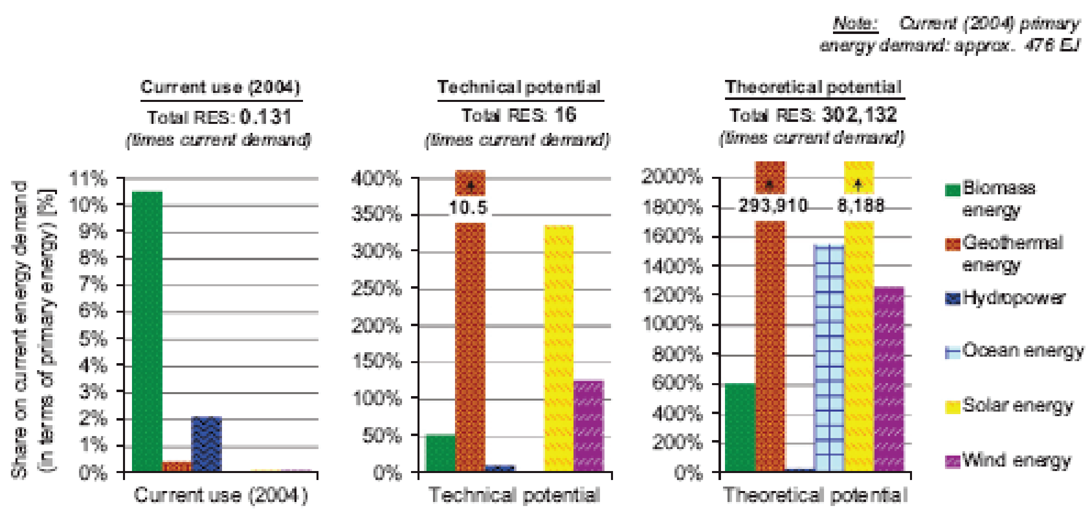


FIGURE 8. Comparison of Technical and Theoretical Potentials for Renewable Energy, 2004 Trend [16]

From the Fig. 8 [16], on the ocean energy during 2004 surprisingly there are not on current use on energy demand [8], and the technical potential is estimated around 10-100 times smaller compare to the others. However, the theoretical potential are high and it helps to determine the use in the near future waiting to be exploited and the process are ongoing in line with the development of knowledge and technology. Besides the fact that promotes wave energy convertor are as follows [9][18]:

- The potential comes from a variety of locations (from shoreline to deep waters).
- Supply and demand- more than 37 % of the world's population lives near the coast line.
- Wave normally happens at all time, hence power conversion can go up to 90% compare to other RE ie. Solar, hydropower and wind.
- Waves can travel large distances with little energy loss

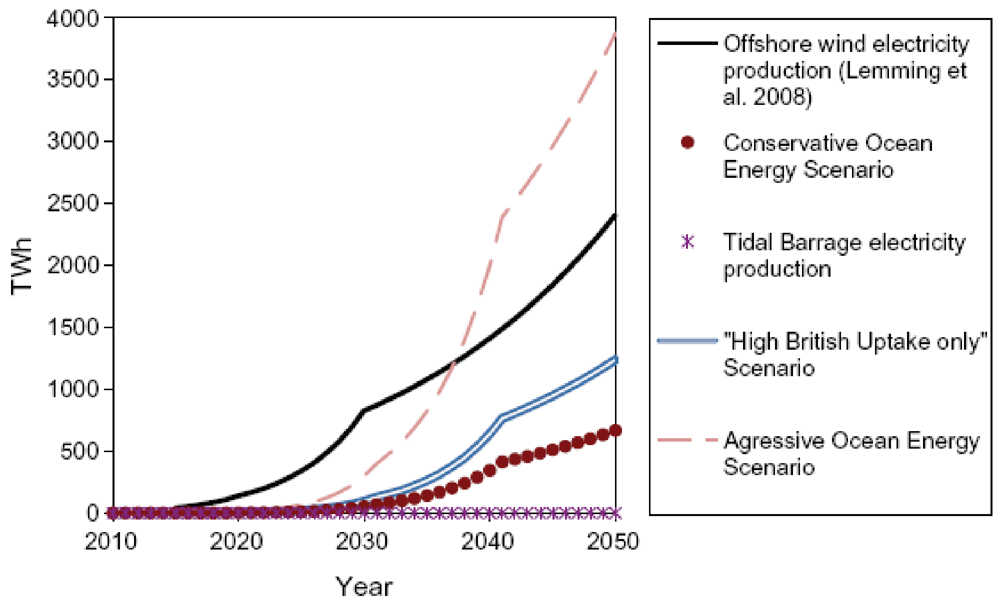


FIGURE 9. Forecast of Future Energy Production [2]

Figure 9 above uses the wind as a reference model for comparison because of the growth rate of ocean energy in 2008 are similar to wind energy in the period 1991-2008 in Denmark. Figure 9 also presents two world's total electricity production from ocean energy scenarios with different outcomes, which conservative ocean energy scenario with 1.7% and aggressive ocean energy scenario 9.84%. It notices that the conservative ocean energy scenario seems more optimistic, but looking at aggressiveness of UK alone planning for massive expansion in ocean energy made it possible [2]. These scenarios also believe followed by other countries.

TECHNOLOGY RELATED

Power Take-Off

The developments of modern technology of ocean energy emerge from prototype to stage installation shows the first 2 types of convertors installation in commercial farms. One is tidal energy convertors (TEC), SeaGen (which are not discuss in this paper) and the other one is wave energy convertors (WEC), Pelamis. Studies on WEC show the difficulties mainly to optimise the absorption power from incident wave and power output. The design of WEC itself must utilise the wave conditions that influence the device behaviour depending on various factors [19]. In order to generate optimum power, the power take-off (normally consist of mechanical, pneumatic or hydraulic) must propose in line with the control methods [10]:

First method is unconstrained continuous control method expressed optimum condition in terms of convolution in time domain. This convolution is a linear transformation between two physical quantities which introduce the simplicity. However, this transformation is non-causal which means that some future information is required, at least one of the physical quantity. Hence, the optimum power can be converted is totally depends on how close this quantity can be predicted [10].

Second is causal control functions which contradict with unconstrained continuous control, where this method do not require the prediction of physical quantities. This method utilised past values information and transfer function is chosen in order to increase the absorption power into optimum under the constraint of the transfer function being causal. However, transfer functions require rational function and may be involve a complex mathematical formula. Both control strategies above are known as continuous methods where the controller can act at any time. Third, discrete control method where it allows controller to act on the system only a limited number during each wave cycle. The advantage of using discrete control is it eased the requirement of high conversion efficiency of the power take-off, compare to continuous power control methods [10].

Types of WEC

There are more than a thousand different proposals for utilization of wave energy that appeared in the patent literature until today. These wave power devices which placed beneath or on the surface of the ocean may include floating structures, pneumatic chambers or oscillating and moving parts, also the fixed (shore based or bottom standing) structures [20]. Typical WEC may classify into three categories which are oscillating water column, overtopping devices and wave activated bodies. Here, in this paper there will be focus detail on the eight main type of WEC which basically being used as basic operation of wave energy converter and all of these devices operate by sending the electricity through cables to the sea floor where it then travels through a cable to shore. The WEC that have been reviewed are:

I) Attenuator

An attenuator operates by capture an energy from the relative motion of its two arms as the wave passes through them. This device also is a floating device which functions in parallel to the wave direction and efficiently rides the waves [21].

(a) (b)

FIGURE 10. (a) Concept of Attenuator (b) Pelamis (Sea Snake) Wave Converter [21]

There were one type of the well-known attenuator calls Pelamis which it is a long cylindrical devices which floating and connected in series where the hydraulic devices ram connecting each section will turn an electric generator [9]. The Pelamis typically installed around 2-10km from the coast and operated in the depth water which greater than 50m. The first offshore Pelamis were developed from the company call Pelamis Wave Power which formerly known as Ocean Power Delivery Ltd. at the European Marine Energy Centre offshore test facility on Orkney. Moreover, the company successfully commissioned three units of Pelamis forming the world's first commercial wave-farm off the coast of Portugal in September 2008 [22]. Usually with the target capacity factor of 25-40 percent, the Pelamis is rated at 750kW depending on the condition at the site project. On average, one device could supply a sufficient power for approximately 500 homes annually [23]. Based on the recent plans for a small wave farm consist of four Pelamis wave converters will cost £10 million in order to be build which is about £2.5 million to build and install each one [24].

II) Point absorber

A point absorber converts the motion of the buoyant top relative to the base into an electrical power. It floating structure absorbs energy from all the directions through its movement that near the water surface. Depending on the configuration of its displacers and reactors the power take-off system may take a number of forms [21].

(a) (b)

FIGURE 11. (a) Concept of Point Absorber (b) The Point Absorber[21]

Point absorber usually are considerably smaller concerning to the diameter compared to it wavelength. This device collects the energy in all directions through its movement and generates an electricity by converting the up-and-down pitching motion of the waves into rotary movements, or oscillatory movements which depending on specific device from the bobbing or pitching action of the device. An example of devices that applied this point absorber concept is OPT's PowerBuoy 150kW technology that demonstrate the main developers of this sort of converters [9].

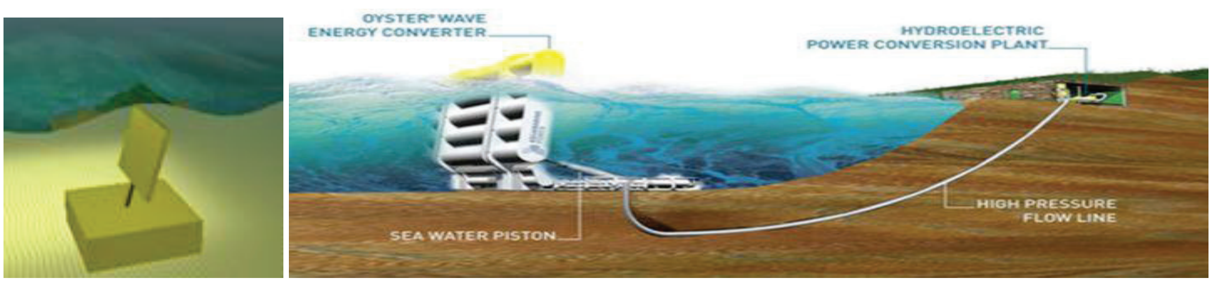
The point absorber concept was acknowledged to be the one of the best WEC since it is:

- Floating; thus the capital cost and maintenance for the obstacles of seabed installation can be ignored
- Has minimal impact on the environment and to the local habitat
- May easily absorb energy from all the direction since it is axially symmetrical.

The different type of point absorber may generate different value of electricity energy such as for MiniBuoy, it can generate 35 Watts continuously and MicroBuoy APB 10 which capable in generate a 10 Watts continuously. Moreover, this device designs to be installed one to five miles offshore in water 100 to 200 feet deep [21].

III) Oscillating wave surge converter

This device operates by using its arm that fluctuate and function as a pendulum mounted on a pivoted joint which react to the movement of water in the waves. The Oscillating wave surge converters generate energy from the movement of water particles and the wave surges within them [21].



(a) (b)

FIGURE 12. (a) Concept of Oscillating Wave Surge Converter [21] (b) Operation of Oyster [25]

Oyster is the best example device applied the oscillating wave surge converter concept which it is:

- Easy for maintenance - There is no pollution produced from this device since it is contains no toxic substances, silent and does not require any other substance apart from the sea around it.
- Flexible and uniqueness- Even in the worst sea condition, the Oyster was successfully continues to generate the electricity and also it will still operate in the sea still conditions which with no waves in the ocean at all.

This device placed offshore in a depth of about 10-12 meters and it is very powerful , the highest power that Oyster can produce is around 300-600kW which depending on the location and Unit’s configuration. Moreover, the single pumping cylinder of this device can deliver more than 170kW which proving that by using the full-scale device the 350kW of electricity can be produced with only two pumping cylinder of the Oyster [25].

IV) Oscillating water column

With the hollow structure, an oscillating water column is a partly submerged and enclosing a column of air on top of a column of water since this device is open to the sea below the water line. The air column were in turn compressed and decompressed since the water column is rise and fall because of the wave movement. Then, the trapped airs were flow to the atmosphere via a turbine which will be able to rotate the direction of the airflow. This turbine rotation were use to generated the electricity [21].

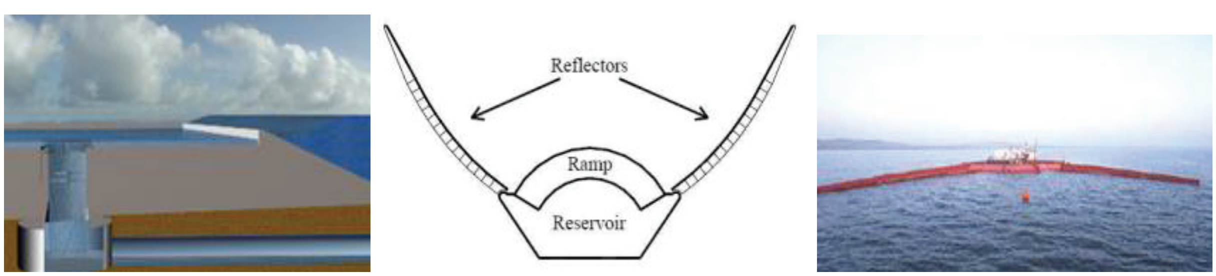
(a) (b)

FIGURE 13. (a) Concept of Oscillating Water Column [21] (b) Prototype of LIMPET Constructed In 2000 on the West Coast Of The Scottish Island Of Islay [26]

The oscillating water column concept only used its structure to operate. For example, LIMPET a prototype that also knows as the onshore water column (OWC) wave energy converter created by Wavegen with Queen's University, Belfast, which was installed on Islay in 1999. This device is capable of generating 500 kW [9][26]. OWC also have been successfully developed in 1910 by the French Praceique-Bochaux which purposely to generate the electricity using the wave energy to supply his home in Royan. The whole concepts of OWC were successfully discovered by Yoshio Masuda, from Japan since 1940 [26].

V) Overtopping/terminator device

An overtopping device which also famous knows as overtopping terminator is categorized as a wave capturer and a large device that instead of using a wave's kinetic energy to generate power like other WEC devices, the terminator captures waves and takes advantage of their potential energy [21][27].



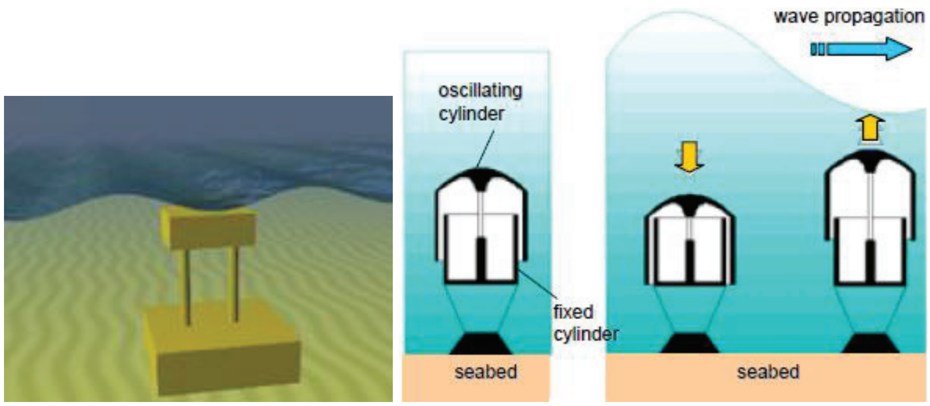
(a) (b)

FIGURE 14. (a) Concept of Terminator Device [21] (b) Wave Dragon Structure and Image [27]

The processes of collecting the energy from the wave started when the waves move towards an overtopping terminator, they bash into its reflectors. Then, these reflectors are attached to the main body of the buoyant tool were angled outward so that it may direct as much wave energy up to the device as possible. The Wave Dragon model as shown in Fig. 14 is the example of these overtopping terminator devices. This device has a rated power of 4-10MW with the average cost of installation for one of these devices is around $10 to $12 Million [27].

VI) Submerged pressure differrential

In general, the location of this device is near to the shore and attached to the seabed [21]. The system of submerged pressure differential device is similar to the power buoy but this device applied the conversion of mechanical energy to electricity in order to produce the electricity needed. The conversion achieved by their movement of the central rod up and down, back and forth which this scenarios will composed a permanent magnet through a fixed coil at the synchronous generator. This operation call Faraday's Law that involve a current induced in the coil and this happen due to the coil cutting through the magnetic field of the permanent magnet. Consequently, the direction of travel find out the currents direction of flow through the coil then lastly produced an alternating current [28].



(a) (b)

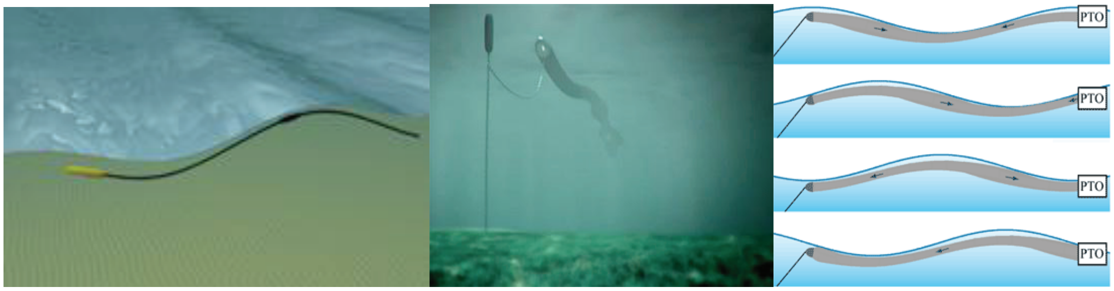
FIGURE 15. (a) Concept of Submerged Pressure Differential [21] (b) The Archimedes Wave Swing [28]

The best example of device that applied this concept is the Archimedes Wave Swing. These systems is advanced when install on a larger scale since it do not cause visual disturbances as it is hidden from the view below the sea surface and also it is taking up little area of the sea, combined with low maintenance and costs make this a very practical solution. One unit of this device can generate up to 2000kW. Thus, one wave farm that consists of hundreds of Archimedes wave swing can generate up to 200MW [28].

VII) Bulge wave

These devices consist of a rubber tube filled with water that moored to the seabed heading into the waves [21]. The Bulge wave were travels at a speed which determined by the material properties and geometry of the tube which a running bulge wave was generated by compress the water-filled rubber tube. One of the common type of bulge wave for WEC is anaconda wave energy converter as shown in Fig. 16. This Anaconda designed purposely to make it bulge wave speed were close to the speed of the external water waves above the shore. So that, the wave energy is gathered since the resonance condition of the bulge grows as they travel along the tube. Moreover, the bulge waves are accompanied by the periodically reversing the flow inside the tube. Thus, the effect of localized squeezing and enlarging help the energy to be extracted indirectly with a Power Take-Off [29].

A pair of duck-bill valve was used as one way of extracting power from this device which this duck-bill valve converted the power into a rectified flow past thru a turbine which located in between high and low pressure of reservoirs. There are a lot of advantages by applying this device as WEC such as the rubber tubes can live forever in the sea and it will be no break, no hinges, no joints plus it is cheap. Generally one farm of anaconda installed more than 20 and one unit of this device was cost nearly 1.5 million dollars. Then, the initial assessments point out that the Anaconda would be rated at a power output of 1 MW [29]. Thus, the total power could generate by one farm of anaconda WEC is up to 20 MW.

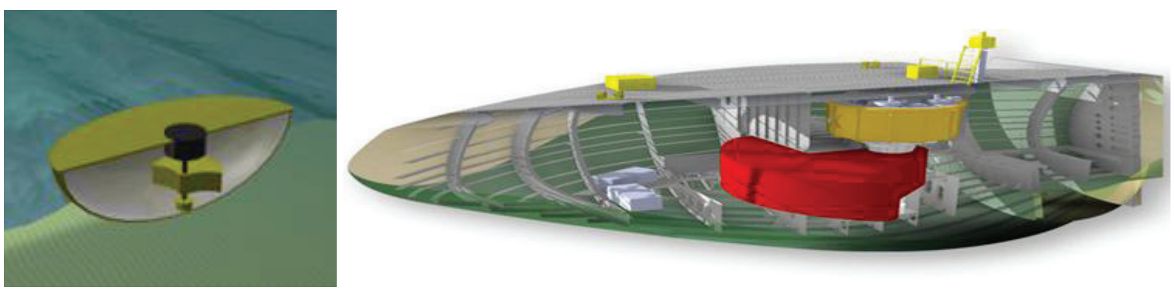


(a) (b)

FIGURE 16. (a) Concept of Bulge Wave [21] (b) Anaconda Wave Energy Converter [29]

VIII) Rotating mass

The energy were captured by the movement of two foams of rotation of the device that heaving and swaying in the waves. This action drives either an eccentric weight or a gyroscope then causes precession and for both cases the movement attached to an electric generator inside the device [21].



(a) (b)

FIGURE 17. (a) Concept of Rotating Mass Wave Energy Converter [21] (b) Body Structure of Penguin [30]

The Penguin is the organic, has a longer lifecycle than an average wind power plant and unique example of the Rotating Mass device which successfully designed by the Wello. This device able to captures the kinetic energy then turning it into usable power while riding the waves. The Penguin is constructed to be reliable, simple and extremely durable so that it is withstand the harsh condition of the ocean environment. In order to be durable and low maintenance all the operational parts are installed inside of Penguin protective cover and the outer of this device were made from the tough recyclable materials. Generally, a single penguin WEC would be rated from 0.5MW to 1MW [30].

TABLE 1. Advantages, limitation and power production of WEC based on system

Systems	Advantages	Disadvantages	Power
Pelamis	-portable -easy maintenance process	-expensive -efficiency around 25%-40%	Power produce 750kW [18]
Power Buoy	-electrical produced continuously from all direction -cheap	-need to be installed at deep sea and far. -Expose to storm	Power produce 1MW [18]
Oyster	-easy maintenance process -can operate in sea still condition -no pollution	-use large area to operate.	Power produce 800kW [9]
LIMPET	-low maintenance -no greenhouse release -near shore -suitable with low wave height	-initial building cost -could be considering an eye sore	Power produce 500 kW [9][18]
Wave Dragon	-simple construction -portable -easy to install	-expensive -limited place to operate	Power produce 11MW [18]
The Archimedes	-does not produce visual disturbance - use basic theory of electrical generation	-not portable -maintenance	Power produce 250kW [9]
Anaconda	-cheap -longer life span	-disturb other ocean user -Use large area	Power produce 1MW [29]
Penguin	-simple design, reliable and extremely durable for harsh environment -very low maintenance cost -portable	-use large area -disturb other ocean user	Power produce 500kW [31]

Table 1 shows the advantages, limitation and power production of WEC based on systems. The power produce values above are varies, which may not accurate and depends on location and size of the device.

INSTALLATION OF COMMON WEC TO THE GRID

One of the most direct ways to measure the development and welfare of society is by measuring their level of energy consumption. It is predicted that there will be 30% increment of global energy consumption by 2040 compared with the one in 2010, and electricity generation will be more than 40% of the global energy consumption [20]. Nevertheless, agreed that traditional energy source is very limited therefore this demand certainly could not be achieved in the near future. In this circumstance, renewable energy plays a key role. The researchers have been made a great effort in development of generators from the renewable sources such as wind and solar generation for the past three decades. However, wave energy is slowly beginning to establish itself and stimulate a great interest from the scientific community and also this energy is another source with high potential energy.

In the thirteenth century, China have been made an early indications of these wave energy by applied them as an apparatus to move the mills. But, the first pattern was not obtained until Girard and Son from France got one in 1700 [9]. The installation of WEC conveys differing challenges that may be addressed by technology transfer from the existing offshore industry. An early wave energy converters were feature induction generators as used in wind generation which the operating commonly at 690V. High voltage connection was required since the transmission to shore is over a long distance [9]. The 11 or 33 kV as shown in Fig. 18 will then be used on board or seabed mounted transformer for connection to the subsea or onshore distribution network. In order to avoid installing transformers at or below the sea surface, generators should be developed to operate at higher voltage. For fixed speed machine, the machine winding rated at 20 kV is available.

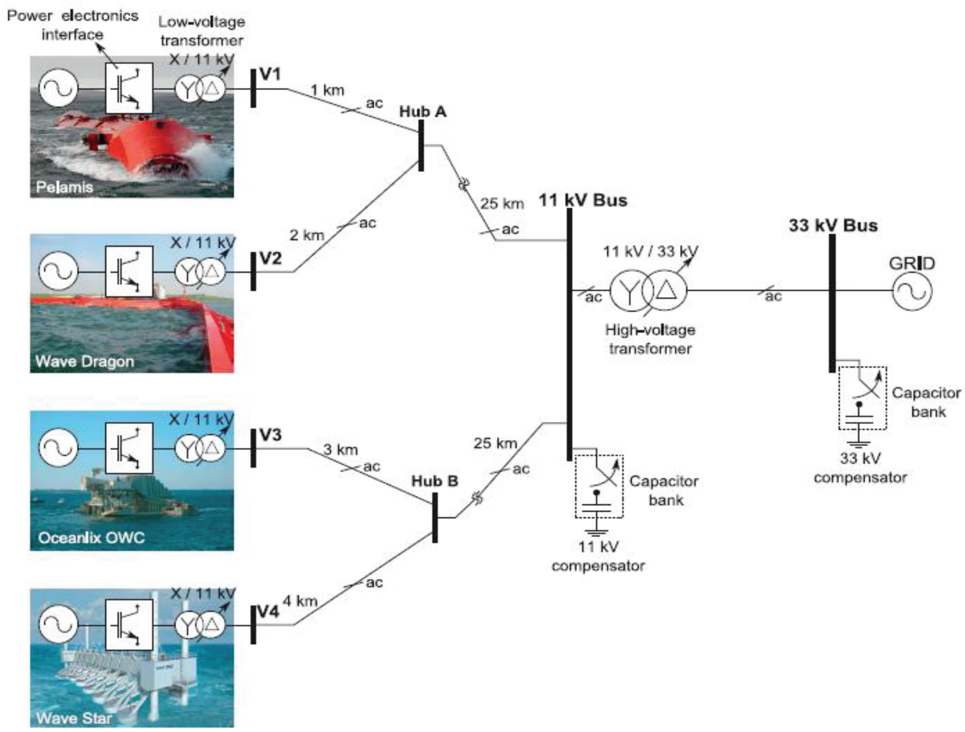


FIGURE 18. Single-Line Diagram of the Wave Hub [9]

In order to guarantee the power produced have a best integrates with the regularly weak rural networks around the coastline, the prospective variable frequency and variable voltage output from wave energy converters (WEC) has to be smoothed. Thus, it is anticipated that by 2020 the coupled power converter and energy storage control strategies of single machines will be install in the interconnected arrays. Furthermore, intelligent voltage and power factor control of distributed generation connected to weak networks, will have to be extended to marine and included more novel permanent magnet generators [9]. Direct current (DC) transmission fit with the multi arrays systems connected to common DC link will become necessary for the large capacity wave farm for the offshore; also combine with energy storage and power condition at shoreline.

The marine energy resource such as wave is most concentrated in areas where access to the transmission system is limited, for example in the United Kingdom location such as off the Western Isles, off Orkney and Shetland and in the south west of England. The implication and problem such as low quality of supply and operating within these limits area can restrict the amount of wave generation that connected in delivering the distribution network. Still, the solution for this problem is quite possible but very costly and may evoke public reaction [9].

Furthermore, the interconnection and installation of Common WEC to the Grid will have three steps of conversion; primary conversion which involves pneumatic extraction, hydraulic extraction and direct extraction depends on the type of WEC itself. For secondary conversion it is engage with the air turbine, hydraulic turbine and hydraulic motor and those machines need the rotary generator in order to activate properly and lastly the tertiary conversion is the steps which connect and convert the wave energy to the electrical energy which involve the power converter, transformer and last to the grid as shown in Fig. 19 above. Moreover, in the tertiary conversion step; the transformer will have a step-up function which connected to the output in order to obtain these two targets which i) to increase the voltage level to an suitable level for the transport and connection to the grid and also ii) to guard and protect the devices from possible faults that may arise in the transmission lines or in the grid. Detail operation for the Installation of wave energy converter to the Grid have been describe and explained in the review paper by I. Lopez et al. [9].

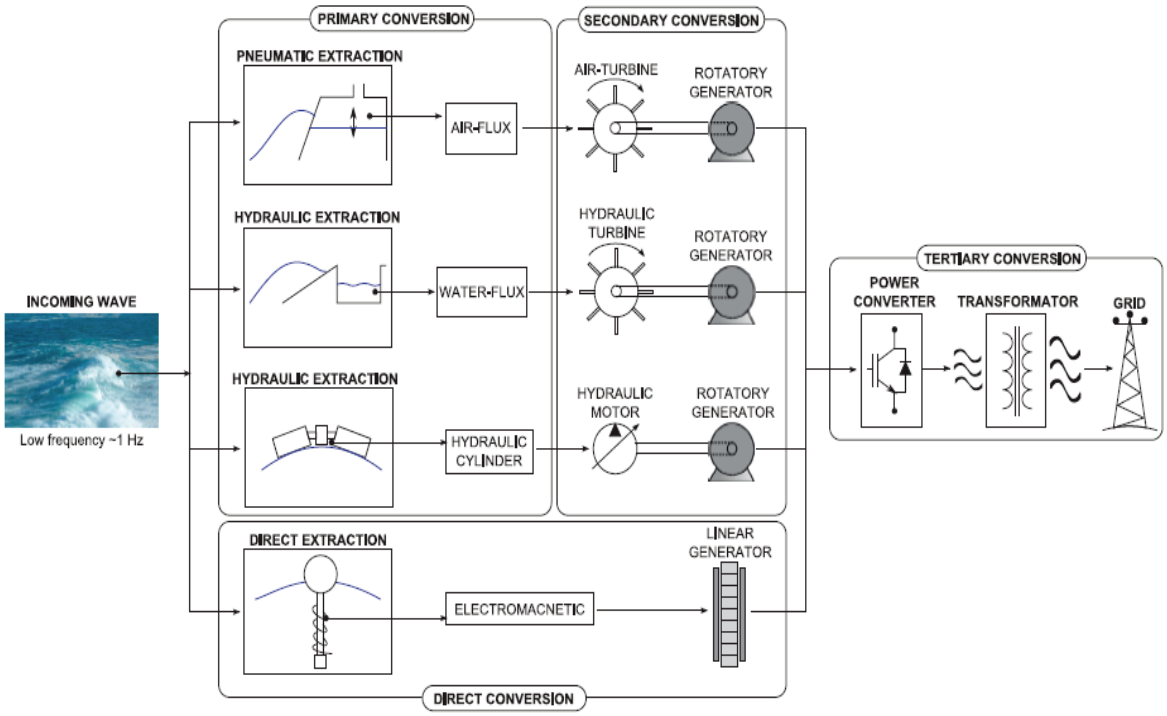


FIGURE 19. Energy Conversion Stages [9]

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