



Wave energy resource assessment and review of the technologies

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Abstract

Increase in human population has increased the demand for more energy. Technical improvement in transport and electrical appliances gives a lot of facilities to our life nowadays. Still we need to generate or convert this energy. Energy generation based on conventional technologies is always accompanied by environmental pollution. It gives overheating and greenhouse effects that later result in biosphere degradation. Nowadays sea wave energy is being increasingly regarded in many countries as a major and promising resource. It is renewable and environmentally friendly. In this paper wave parameters related to wave energy is analyzed. Then the paper describes the development of many different types of wave-energy converters. Several topics are addressed; the characterization of the wave energy resource, range of devices and how such devices can be organized into classes.

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1. Introduction

World energy consumption is expected to rise considerably over the next decades. This increase is also notably in some Asian countries. Energy consumption for Malaysia will increase in the same pattern. The reason is that, as in other parts of the world, more Malaysians are using modern appliances for their daily life. According to a classification, energy sources can be investigated in two groups as renewable energy sources and nonrenewable ones [1]. Researchers and policy makers agree that fossil fuel is depleting and conventional energy sources are always accompanied by environmental pollution. Thus researchers all over the world are actively searching for renewable and environmental friendly resources. Some researchers and policy makers claim that 70% of the world energy could be obtained from renewable resources if active researches are made for another forty years [1]. Energy can be obtained from biomass, hydropower, solar, geothermal, wind [2] and wave.

This article aims to present the characterization of the wave energy resource for the purpose of its utilization as a renewable energy in Malaysia and reviews the available wave energy conversion methods and equipments.

1.1 Wave energy

Increasing global energy consumption is now known to have serious environmental implications and recent years have seen a drive to produce energy from renewable sources. The wave energy is being increasingly regarded in many countries as a major and promising resource since 1970s. Comparing ocean-wave energy with its origin, wind energy, the former is more persistent and spatially concentrated. Ocean wave energy is an abundant renewable resource. It is free from environmental pollution and continuous as waves are never going to cease [3] as long as there is pressure difference on sea surface. The potential market for wave energy is huge although wave energy resource is distributed unevenly to different regions in Malaysia. Thus a promising source of renewable energy for Malaysia is from the oceans and interest in developing machines to convert energy from waves is steadily increasing.

The possibility of converting wave energy into usable energy for human purposes has inspired numerous inventors for more than two centuries [4, 5], very few of which will progress through to the ultimate goal, that of commercialization. Although a number of successful devices have been installed at shoreline locations, the true potential of wave energy can only be realized in the offshore environment where large developments are conceivable. The majority of wave energy converters (WEC) have been conceived as offshore devices, where the highest wave energy densities are found. The negative side is that devices in offshore locations have more difficult conditions to contend with WEC. Shoreline technologies have the benefit of easy access for maintenance purposes, whereas offshore devices are, in most cases, more difficult to access.

2. Wave theory

The wave energy is very much suited for countries with vast coast line and high waves approaching the shore [3]. Waves are produced indirectly. The waves are produced by sun by the following processes: The total power of solar radiation incident on Earth atmosphere is tremendous. When heated by sun, water evaporates, reducing the onset pressure. When there is pressure difference, wind flows along the surface. The large movement of air masses, vapour and water volumes creates the wind wave. Thus the main primary energy source for all processes near the earth surface is the sun.

The movements of the sea surface, or known as sea waves is also caused by external effects such as earthquakes, marine vehicles or attraction of gravity of the moon and sun. Sea waves due to the wind are more continuously compared to sea waves formed by other effects and therefore, they are considered primarily in obtaining energy. Wave energy potential, as it is found in nature, is called natural potential. Technical potential is the transformed form of the natural potential to usable energy by technological systems. The economic potential is the economically defined amount when compared to the other energy sources [1].

In the past numerous researches [6-10] have been undertaken to quantify the amount of wave power available at a particular location based on the values of significant wave height (H_s), peak wave period (T_p) or energy wave period (T_e). All these studies examined the combined effect of H_s , T_p or T_e on the power estimation with a general aim to provide joint scatter plots. The assessment of the wave energy resource is a basic prerequisite for the strategic planning of its utilization and for the design of wave energy devices. The characterization of the wave climate had been done before for other purposes (navigation, harbor, coastal and offshore engineering); however, the required information does not coincide with what is needed in wave energy utilization planning and design. The wave energy level is usually expressed as power per unit length (along the wave crest or along the shoreline direction); typical values for "good" offshore locations (annual average) range between 20 and 70 kW/m and occur mostly in moderate to high latitudes. Seasonal variations are in general considerably larger in the northern than in the southern hemisphere [11], which makes the southern coasts of South America, Africa and Australia particularly attractive for wave energy exploitation.

As a mathematical illustration of wave-energy extraction, we shall for simplicity we consider wave power. The wave power estimation using the wave data will give an account of the distribution of wave energy in space and time. Since the last few decades, the hydrodynamics of ocean waves have been thoroughly studied and now it is possible to determine the energy content of the sea with the help of large amount of wave data collected. The power in wave can be expressed by the formula [12]

$$P = 0.55 H_s^2 T, \text{ kW/m of crest length} \quad (1)$$

where H_s , is the significant wave height in meter and T , is wave energy period in seconds.

3. Malaysia wave data

The typical waves of Malaysian coast were selected to characterize the wave energy potential. The values of significant wave height, peak period, and mean wave direction within the period 2008–2010 were analyzed. The results from the measurements are presented in the form of figures and tables. They include the classes of significant wave height, maximum wave height, mean and peak periods and also the wave direction distributions, corresponding to whole years. In order to show the random variability in the actual situation, the joint significant wave height (H_s) and peak wave period (T_p) distribution was tabulated considering six significant wave height intervals and eight peak period intervals as shown in Table 1, leading to forty eight combined intervals. Ascribing each two-hourly sea state to the appropriate interval, the percentage of the total time in an average year corresponding to the different intervals was obtained. The results are shown in Table 1.

Table 1. Percentage of total time in an average year corresponding to sea states with different H_s and T_p

H_s (m)	Peak time, T_p (s)							
	≤ 2	2 - 4	4 - 6	6 - 8	8 - 10	10 - 12	12 - 14	> 14
≤ 0.2	1.21	4.02	5.00	1.16	0.18	0.05	0.00	0.00
0.2 – 0.6	0.71	15.14	25.11	5.65	2.90	0.46	0.27	0.02
0.6 - 1.0	0.00	0.36	3.20	13.49	1.49	0.23	0.00	0.00
1.0 – 1.4	0.00	0.00	0.32	5.48	4.18	1.41	0.00	0.00
1.4 – 1.8	0.00	0.00	0.16	1.94	2.70	1.53	0.00	0.00
> 1.8	0.00	0.00	0.00	0.44	0.57	0.27	0.00	0.00
Total (%)	1.92	19.52	33.79	28.16	12.02	3.95	0.27	0.02

A similar analysis was carried out combining mean wave direction (θ_m) and significant wave height. Eight sectors were considered for the mean wave direction. With the same significant wave height intervals as Table 1, forty eight combined intervals of the (H_s, θ_m) distribution were considered. The sea states were ascribed to these intervals and the corresponding time percentages computed for the same location is given in Table 2.

For the characterization and computation of wave energy, the wave spectra were assumed to be the same during the sampling interval of two hours. The wave energy in the sea states of each of the combined (H_s, T_p) and (H_s, θ_m) intervals was calculated and referred to a one-year period to obtain the value in an average year; the total annual wave energy was obtained as the sum of all the intervals.

Table 2. Percentage of total time in an average year of sea states in different ranges of H_s and θ_m

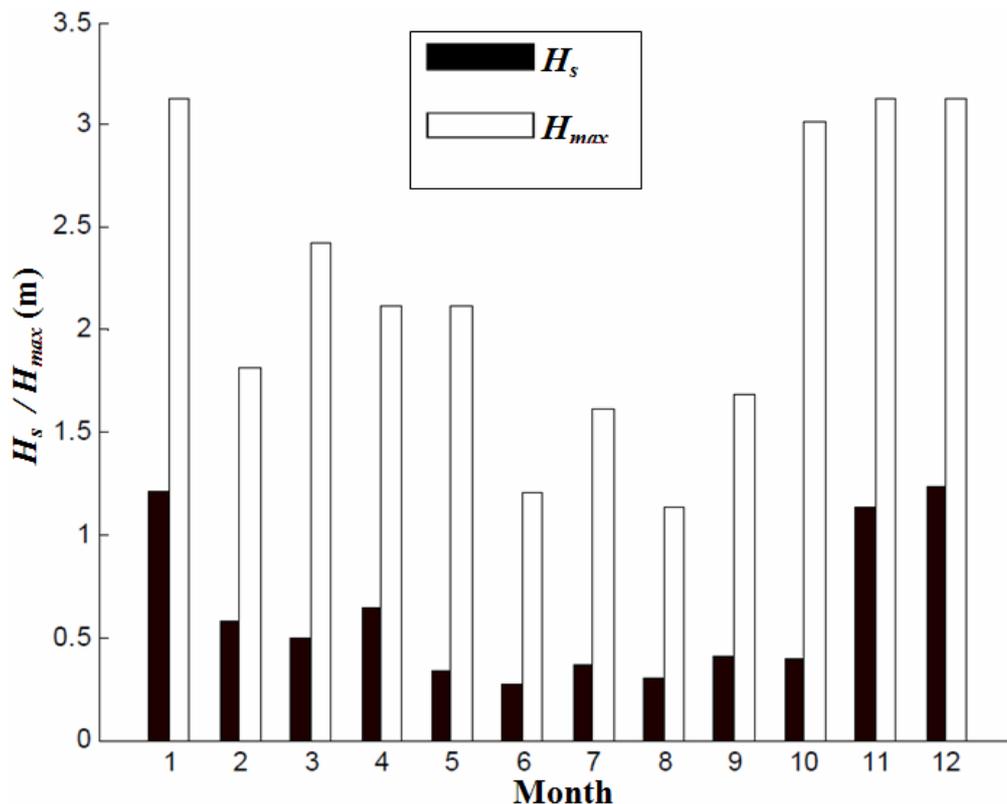
H_s (m)	N	NE	E	SE	S	SW	W	NW	Total (%)
≤ 0.2	2.17	2.51	1.21	1.26	1.07	0.94	1.05	1.42	11.62
0.2 – 0.6	11.55	7.42	5.74	1.10	5.48	6.92	6.09	3.88	50.18
0.6 - 1.0	13.52	1.43	0.41	0.05	1.53	0.85	0.46	0.96	19.20
1.0 – 1.4	7.44	2.86	0.14	0.00	0.05	0.09	0.13	0.69	11.40
1.4 – 1.8	4.02	2.12	0.00	0.00	0.00	0.00	0.00	0.18	6.32
> 1.8	0.87	0.41	0.00	0.00	0.00	0.00	0.00	0.00	1.28
Total (%)	39.57	16.75	7.29	2.41	8.13	8.80	7.73	7.13	100.00

Table 3 shows the results of an average year joint H_s and wave power (P) distribution with wave power data expressed in percentage of the total power corresponding to each interval. More than sixty percent of the annual wave energy is provided by less than 1.2 m significant wave height.

Figure 1 shows monthly averaged H_s and H_{max} variation. It is observed that maximum wave heights varies from 1.13 m to 3.13 m and monthly mean significant wave height varies from 0.27 m to 1.24 m.

Table 3. Percentage of total time in an average year corresponding to sea states with different H_s and P

H_s (m)	Wave power (kW/m)							
	≤ 2.5	2.5 - 5	5 - 7.5	7.5 - 10	10 - 12.5	12.5 - 15	15 - 17.5	> 17.5
≤ 0.2	11.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2 - 0.6	50.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6 - 1.0	14.25	4.95	0.00	0.00	0.00	0.00	0.00	0.00
1.0 - 1.4	0.05	4.93	4.33	2.08	0.00	0.00	0.00	0.00
1.4 - 1.8	0.00	0.00	0.66	3.04	1.64	0.75	0.23	0.00
> 1.8	0.00	0.00	0.00	0.00	0.14	0.44	0.41	0.30
Total (%)	76.10	9.88	4.99	5.12	1.78	1.19	0.64	0.30

Figure 1. Variation of monthly averaged H_s and H_{max}

4. Wave energy converter technologies

Impressed by the power of ocean waves, inventors have, for more than two centuries, proposed many different devices for utilising wave power. Although these techniques are generally not as far developed yet, it is likely that wave power will become at least as important as wind and hydropower [13]. The many different proposals and principles for wave energy conversion may be classified in several ways.

Unlike large wind turbines, there is a wide variety of wave energy technologies, resulting from the different ways in which energy can be absorbed from the waves, and also depending on the water depth and on the location (shoreline, near-shore, offshore). These are useful for considering the differences and similarities between various WECs. They may be classified according to location (off-shore, near-shore or onshore; floating, submerged or bottom-standing), type of energy conversion machinery (mechanical, hydraulic, pneumatic or directly electrical) and type of energy for end use (electricity, water pumping, desalination of seawater, refrigeration, water heating, propulsion).

WECs may also be classified according to their horizontal extension and orientation. If the extension is very small compared to a typical wavelength, the WEC is called a point absorber. On the contrary, if the extension is comparable to or larger than a typical wavelength, the WEC is called a line absorber, but the

terms attenuator and terminator are more frequently used. A line absorber is called an attenuator or a terminator if it is aligned parallel or normal to the prevailing direction of wave propagation, respectively. Recent reviews identified about one hundred projects at various stages of development. The number does not seem to be decreasing: new concepts and technologies replace or outnumber those that are being abandoned [14].

4.1 The oscillating water column (fixed-structure and floating-structure)

The first oscillating water column (OWC) converters deployed in the sea were floating. The air flow displaced by the motion of the OWC drives an air turbine, which has been considered for larger scale energy production. The floating OWC devices are largely free to oscillate or tension moored to the sea bed shown in Figure 2 [15]. In general the fixed structure devices stand on the sea bottom or are fixed to a rock. Shoreline devices have the advantage of easier installation and maintenance. The less energetic wave climate at the shoreline can be partly compensated by natural wave energy concentration due to refraction and diffraction. The typical first generation device is the OWC. The OWC device comprises a partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water free surface. The oscillating motion of the internal free surface produced by the incident waves makes the air to flow through a turbine that drives an electrical generator. The design and construction of the structure are the most critical issues in OWC technology, and the most influential on the economics of energy produced from the waves, the civil construction dominates the cost of the OWC plant.

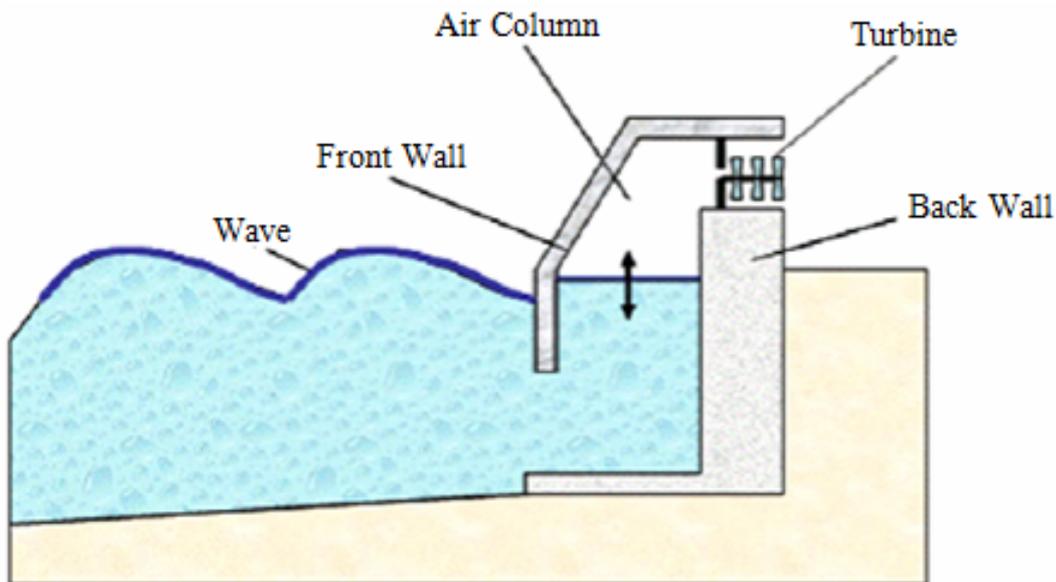


Figure 2. The oscillating water column [15]

4.2 Oscillating body systems

Offshore WEC devices are basically oscillating bodies, either floating or fully submerged. They exploit the more powerful wave regimes available in deep water (more than 40 m). Offshore WECs are in general more complex compared with oscillating water column systems. This, together with additional problems associated with mooring, access for maintenance and the need of long underwater electrical cables.

4.2.1 Fully submerged heaving systems

A fully submerged heaving device (Archimedes Wave Swing), consists of an oscillating upper part (the floater) and a bottom-fixed lower part (the basement) shown in Figure 3 [16]. The floater is pushed down under a wave crest and moves up under a wave trough. This motion is resisted by a linear electrical generator, with the interior air pressure acting as a spring.

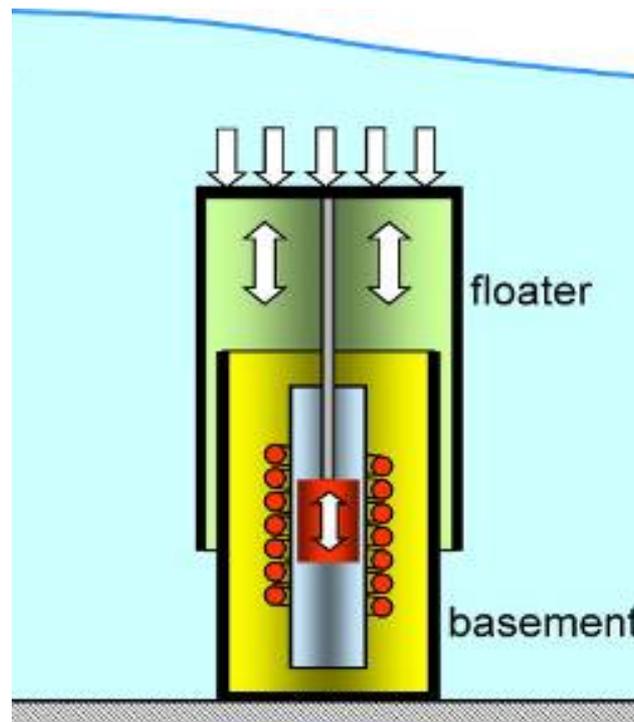


Figure 3. The Archimedes Wave Swing [16]

4.2.2 Single-body heaving buoys and two-body heaving systems

The simplest oscillating-body device is the heaving (i.e. the energy conversion is associated with a relative translational motion) buoy reacting against a fixed frame, in most cases, such systems are conceived as point absorbers shown in Figure 4 [17]. An alternative design is a buoy connected to a bottom-fixed structure by a cable which is kept tight by a spring or similar device. The relative motion between the wave-activated float on the sea surface and the seabed structure activates a power takeoff (PTO) system.

4.3 Pitching devices

The oscillating-body wave energy converters are nominally heaving systems. There are other oscillating body systems in which the energy conversion is based on relative rotation (mostly pitch) rather than translation. Basically it is a cam-like floater oscillating in pitch.

The Pelamis (Figure 5) is a snake-like slack-moored articulated structure composed of four cylindrical sections linked by hinged joints and aligned with the wave direction. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors driving four electrical generators. Gas accumulators provide some energy storage.

All large-scale RE conversions are area demanding and therefore it is always in conflict with other interests. The McCabe Wave Pump consists of three rectangular steel pontoons hinged together, with the heaving motion of the central pontoon damped by a submerged horizontal plate [18] (Figure 6). Two sets of hydraulic rams and a hydraulic PTO convert the relative rotational motions of the pontoons into useful energy.

Another type of device based on the totally enclosed hull concept is the Frog. The PS Frog Mk 5 (Figure 7) consists of a large buoyant paddle with an integral ballasted handle hanging below it [19]. The waves act on the blade of the paddle and the ballast beneath provides the necessary reaction. When the WEC is pitching, power is extracted by partially resisting the sliding of a power-take-off mass, which moves in guides above sea level.



Figure 4. Heaving buoy [17]

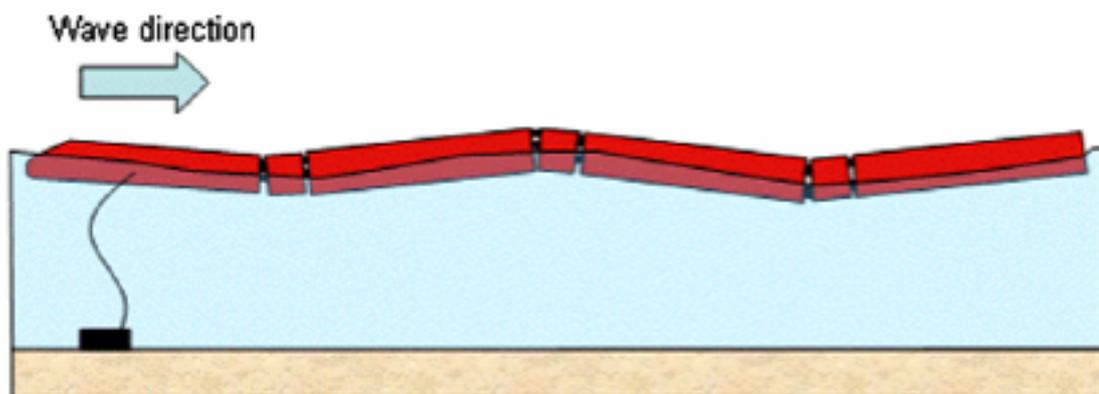


Figure 5. The four-unit of Pelamis wave farm [15]

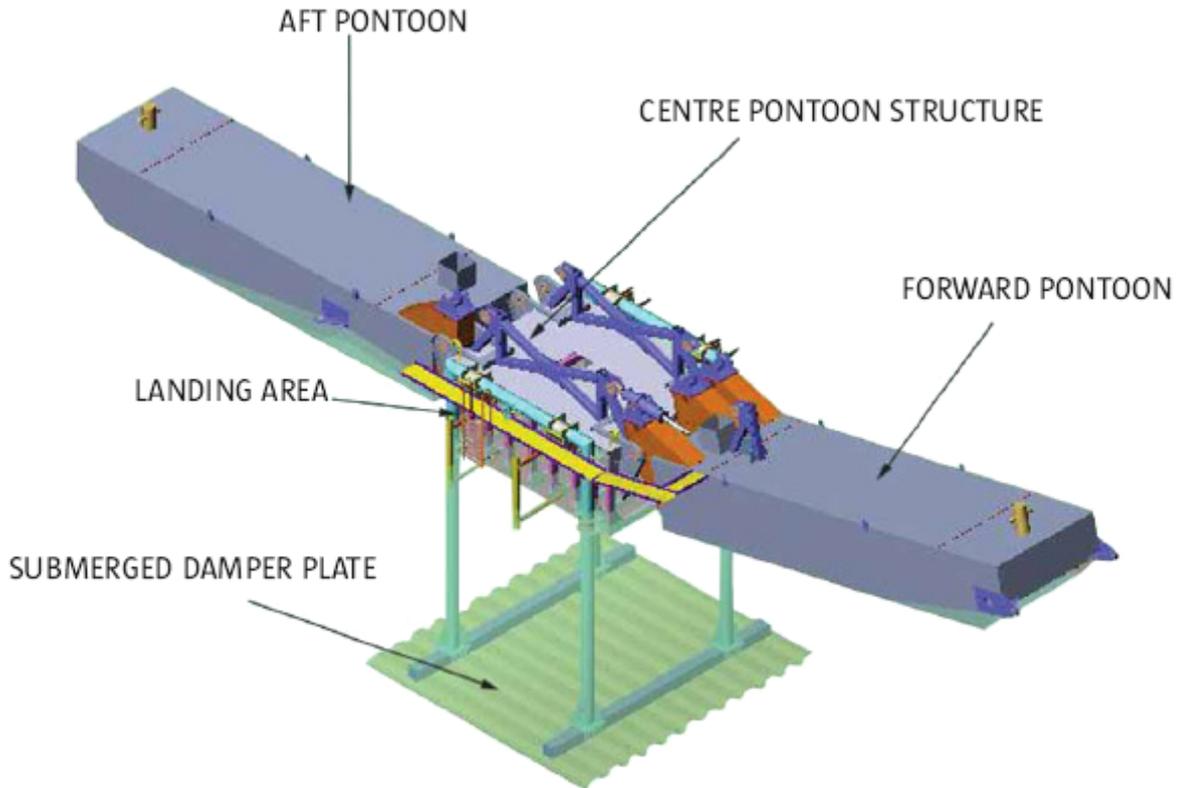


Figure 6. The McCabe Wave Pump [18]

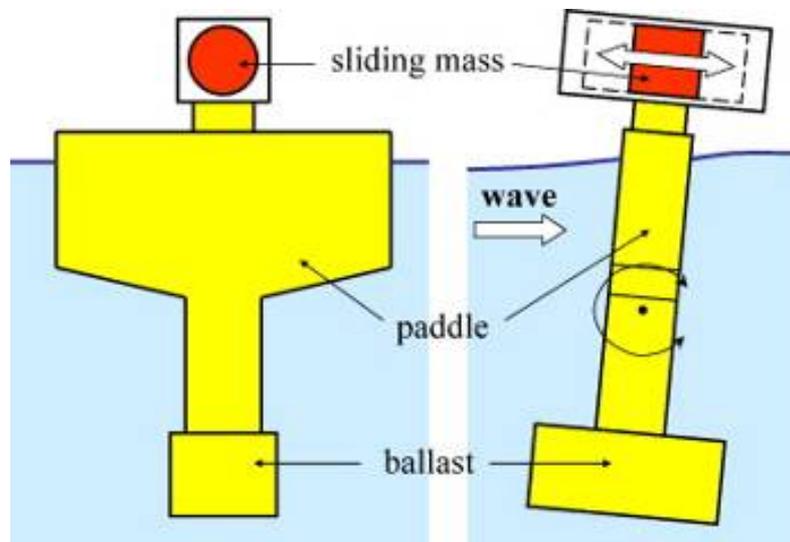


Figure 7. Schematic front and side views of the PS Frog Mk 5 [19]

4.4 Overtopping converters

A different way of converting wave energy is to capture the water that is close to the wave crest and introduce it, by over spilling, into a reservoir where it is stored at a level higher than the average free-surface level of the surrounding sea. The potential energy of the stored water is converted into useful energy through more or less conventional low-head hydraulic turbines. The hydrodynamics of overtopping devices is strongly non-linear, and, unlike the cases of oscillating body and OWC wave energy converters, cannot be addressed by linear water wave theory.

In the overtopping converters, the incident waves overtop a sloping wall (ramp) and fill a reservoir where water is stored at a level higher than the surrounding sea. This is the case of the Wave Dragon, an offshore converter, whose slack-moored floating structure consists of two wave reflectors focusing the incoming waves towards a curved ramp, a reservoir and a set of low-head hydraulic turbines (Figure 8) [20]. The water enters the reservoirs through long horizontal openings on the breakwater sloping wall, at levels corresponding to the reservoirs, and is run through a multi-stage hydraulic turbine for electricity production.

In most of the cases, energy generated by wave alone is not enough. For this case hybrid the wave energy with some other source of energy is recommended. One of the examples is in water supply application by researchers in Portugal and Brazil [21].

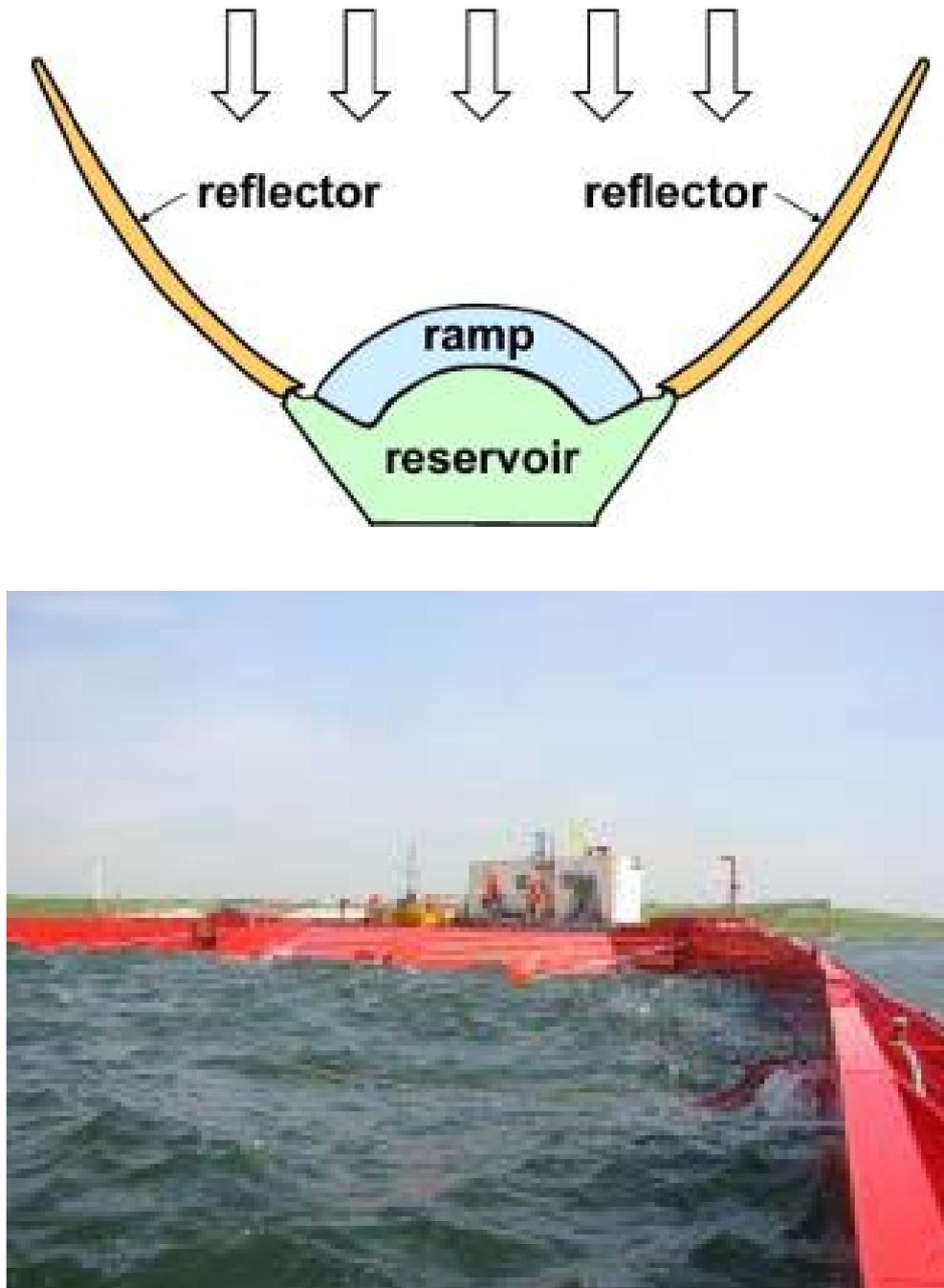


Figure 8. Photo and schematic representation of Wave Dragon [20]

5. Conclusion

The main disadvantage of wave power is its largely random variability in several time-scales, from wave to wave, with sea state, and from season to season. The assessment of the wave energy resource is a basic prerequisite for the strategic planning of its utilization and for the design of wave energy devices. The present situation shows a wide variety of wave energy systems, at several stages of development, competing against each other, without it being clear which types will be the final winners. In the last few years, interest in wave energy utilization has been growing rapidly in all over the world. In general, the development, from concept to commercial stage, has been found to be difficult, slow and expensive process. The high costs of constructing, deploying, maintaining and testing large prototypes under harsh environmental conditions, has hindered the development of wave energy systems. In this paper, we have discussed some wave parameters that are related to transport, generation and variability of wave energy in the sea. Many different types of wave-energy converters have been discussed. They are classified into different groups, according to which oscillation modes, according to applied method of force reaction and according to type of wave-oscillator interface. In order to develop a commercial WEC is not a straightforward task. Many inventions still have to be made, and many challenging problems need to be solved.

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