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Ocean Wave Energy Converters: Concepts, Types and Mathematical Modeling

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Abstract: *Ocean waves are a promising source of enormous energy. They are mighty and powerful. This abundant source of energy is largely untapped. This energy can be captured and converted for useful human purposes, mainly electricity by means of Wave Energy Converters (WECs). Different types of WECs – each with their own working principles - are being proposed to extract energy from the oceans. This paper discusses the different concepts and a variety of types of WECs that are in developmental or in deployed stages. Also, a mathematical modeling of a floating type WEC for optimization of energy capture is presented and the results are discussed.*

Keywords: *Ocean Wave Energy, Wave Energy Converters, Mathematical Modeling.*

1. INTRODUCTION

The depletion of fossil fuels and the increasing awareness of renewable energy has made ocean wave energy a promising source of renewable energy. The energy from the ocean comes in different forms: waves, tides, currents, salinity gradients, thermal differences and geothermal vents. The globe is filled with approximately 70% of water. This vast body of water is dependable, clean, continuous and thus eternal which makes it an incredible source of energy. Winds are formed due to the uneven heating of the earth's surface. These winds blow over the ocean surface which produces waves and is converted into wave energy carrying unimaginable power in them for long distances with little energy loss [1].

This wave energy is dependent on the wind speed, the wind period and the distance over which it blows –called fetch - and the water depth [2]. This power can be predicted for day to day and season to season. The amount of energy ocean waves carry within themselves and hit the coasts is estimated to be about 8, 000-80, 000 TWh/y [3]. This power can be captured and converted by different means for human purposes. It is estimated that if only a small fraction of this abundant energy can be captured and converted, it would meet the energy requirements of the entire world.

2. WAVE CHARACTERISTICS

For simple monochromatic waves, water waves are considered to travel in an approximate sinusoidal path along the sea surface. They can be characterized in terms of wavelength λ, wave period T and wave height H. These parameters (in deep waters) are related as:

$$\lambda = \frac{gT^2}{2\pi} \qquad (1)$$

'g' being the acceleration due to gravity.

The wave velocity 'C' is given by

$$C = \frac{\lambda}{T} \qquad (2)$$

Wave power could be determined by wave height, wavelength, and water density as given below:

$$P = \frac{\rho g}{64\pi} H^2 T \approx \frac{1}{2} H^2 T \qquad (3)$$

where P is the wave energy flux per unit wave crest length (kW/m); ρ is the mass density of the water (kg/m^3); g is the gravitational gravity (m/s2); H is the wave height (m) and T is the wave time cycle (s). But, real sea waves are irregular in nature. They are random in height, period and direction. However, the real sea characteristics (of a sea state) remain constant for a fixed period of time. Statistical parameters are used to describe such sea states. For wave height, the root mean square H_{rms} or significant wave height H_s ($\sim 4H_{rms}$) is used. For the wave period, wave energy period T_e is used. Wind climates are responsible for waves; with a knowledge of wind climates, sea conditions can be calculated using the Pierson-Moskowitz model. This model is used to generate specified sea conditions in a wave tank or to produce waves in them. The energy distribution S as a function of wave frequency f is given by

$$S(f) = \frac{A}{f^5} \exp\left(-\frac{B}{f^4}\right) \qquad (4)$$

where, A and B are constants. The spread of wave direction is called the directionality factor which can be represented as the fractional amount of power in the random sea that can be intercepted by a uni-directional wave energy device. The following equation provides description of the sea states including spread in wave direction θ - which can also be used in wave tank tests.

$$DF = \frac{\int P(\Theta)\cos(\Theta).d\Theta}{\int P(\Theta).d\Theta} \dots \quad (5)$$

where $P(\Theta)$ is the average power of a wave travelling in the direction of Θ [4].

3. OCEAN WAVE ENERGY CONVERTERS

Most of the energy in a wave is contained near the sea surface and reduces with depth. Thus most of the wave energy devices are designed in such a way that maximum energy can be captured by piercing the waves (by designing the device to float or to bottom stand in the case of shallow waters) [4]. A WEC is a device that extracts energy from the oceans and converts it into useful electrical energy, each with a mechanism of its own. There are different types of WECs proposed, some are in the developmental stages while some are deployed in the sea. However, only a few devices have reached commercialization to this day. Nonetheless, WEC can be classified into four main categories, namely Oscillating Water Columns (OWCs), Terminators, Attenuators and Point Absorbers. The OWC devices can be further classified into floating and fixed types. It works on the principle of wave air pressurization. The terminator devices are placed in perpendicular direction to the incident waves. The attenuator devices are placed in such a way that it is parallel to the incident wave. Point Absorbers harvest energy from all directions. A brief description of different types of WECs can be had from [5]. A summary of different concepts of WECs is shown in figure 1 [6].

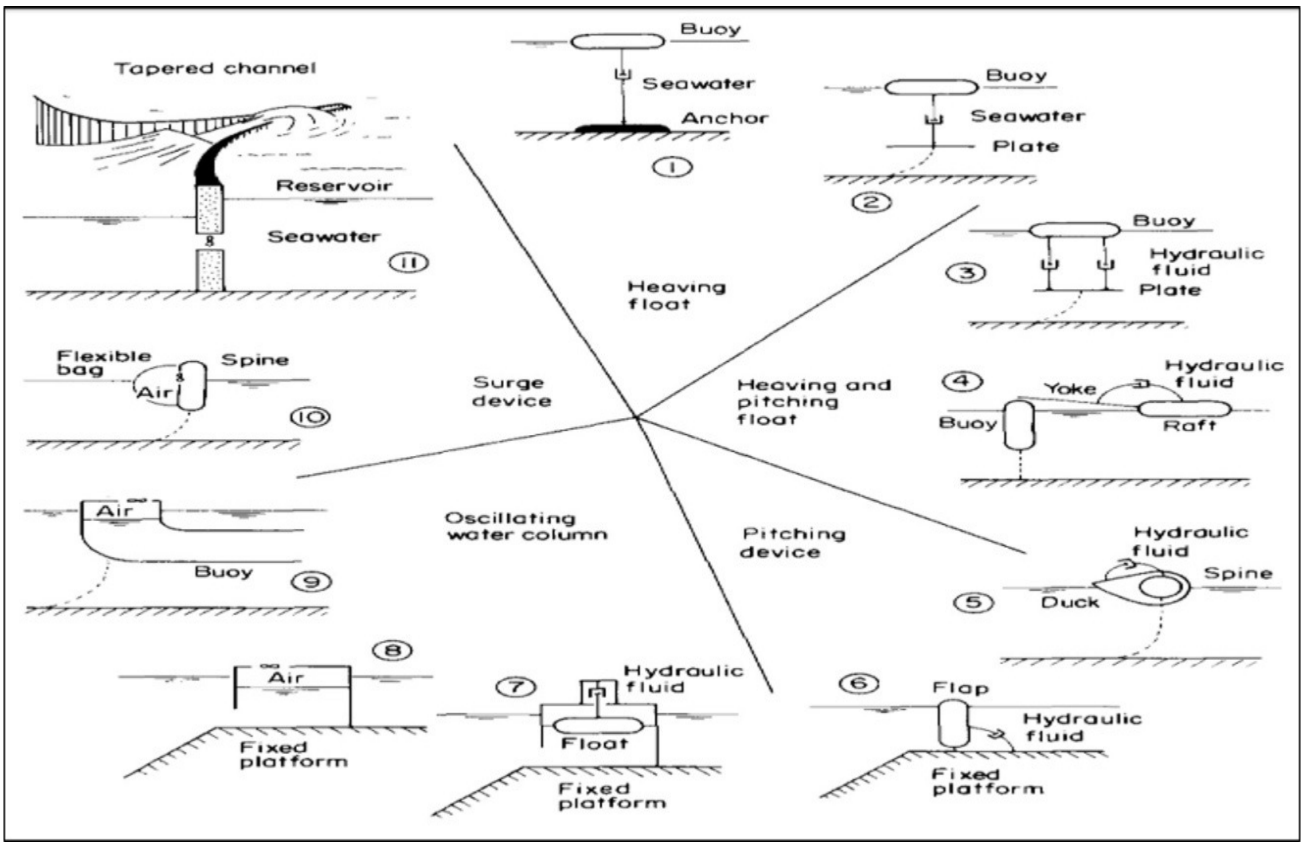

Fig. 1. Different concepts of WECs

4. MATHEMATICAL MODELING:

Mathematical modeling describes about a system using mathematical concepts and language. The aim of mathematical modeling is to study the dynamic behavior of the physical system not yet built. This reduces the cost and time in analyzing the system dynamics. Mathematical modeling writes the script from which specifications are established, design decisions made, prototype models constructed and tests performed with varying parameters and final decisions made. With the growth of modern technology and the powers of scientific computing, mathematical modeling becomes the crux of predicting and analyzing the system dynamics. The modeling process for this purpose usually differs for different physical mediums, but table 1 shows the general order which should be considered when modeling a system. Stages I-III are for analysis and stage IV is for design purposes [7].

TABLE 1: Stages of Mathematical Modeling [7].

Stage	Process
Stage I	Physical Modeling
Stage II	Mathematical Modeling
Stage III	Study the Dynamic Behavior
Stage IV	Design

5. CONCLUSIONS

In an era of renewable energy, ocean wave energy is a promising source. Despite many converters and technologies, only few prototypes have reached the final design status and deployment. Ocean wave energy is yet to find the final light of standard commercialization and filling the national grid with electricity. Nevertheless, the future looks bright with many scopes and possibilities with modern technology. Mathematical modeling plays a key role in writing the script of new possible designs of systems and to study their dynamic behavior with the support of modern technology, thus enabling to understand the advantages and pitfalls of different aspects of the system design and to look into the right direction of optimization to produce electricity.

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