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A Novel Wave Energy Harvesting System for Ocean Sensor Network Applications

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Abstract

This paper represents a solution for avoiding a common hurdle of harvesting ocean energy using Oscillating Water Column that, though being an efficient technology OWC based harvesters often suffers from performance disruption due to rough sea weather. The solution reveals an idea for a completely closed, double chambered, half water filled oscillating water column with two bidirectional air turbines inside, which shows efficient performance in the bad weather condition as well as in general. The system has the unique feature that, it produces electric power without any interaction with outside ocean water or atmospheric pressure and having a simple, closed structure that can be build using the lower vessel type part of any old ship or boat, adds extra facilities like cost effectiveness and less maintenance effort. Offshore ocean environment monitoring wireless sensor network or floating projects like fish farm can use this system for powering the sensor nodes used for measuring temperature, ph buffer, salinity.

***Keywords**: Closed OWC, Wave energy converter, Sensor Nodes*

1. Introduction

Ocean which covers most of the surface of the world (almost 71%) is full of resources [1]. To utilize the resources in efficient ways to be used for mankind, the ocean area needs to be monitored first. Monitoring will include checking climate changes, detecting pollution of the environment which effects living species under water etc. recently this is performed by Wireless sensor networks consisting of thousands of sensor nodes, whereas each node containing a processing unit, a transceiver, memory, a battery and sensors [2]. Besides this, floating projects like fish farm uses different sensor nodes so that these can be remote controlled from far land. Most of these sensor nodes use batteries for power supply that becomes troublesome for prolonged existence of the system since the batteries have specific lifetime after which they need to be changed. To avoid this difficulty extracting the energy for monitoring the ocean from the ocean it is the best idea.

With a view to this, different types of wave energy harvesting systems are available now a day. Among many types of offshore and near shore wave energy harvesting devices, Oscillating Water Column (OWC) is the most successful and extensively studied technology for extracting energy from ocean waves [3]. But most of these are for larger power generation which are complex and of bigger sized with high costing. And also, they cannot perform at their maximum efficiency in rough weather condition.

Harnessing energy from ocean waves even in the harsh sea weather has always been a challenge for off shore wave energy harvester devices. This paper describes a new idea of closed type OWC which has been designed specially keeping in mind that it can withstand bad sea weather and obviously be cost effective and will require less

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maintenance. This is an off shore energy harvesting device for electric power generation. As it is closed type OWC water wouldn't enter inside it and so it will not be a matter of keen observation or regular maintenance.

2. Oscillating Water Column

2.1. Background

An increasing population together with its improving living standard is driving up the consumption of energy and it is consecutively diminishing the resources like oil, coal and natural gas. Side effect like environmental pollution have put an end to the fossil fuels and now renewable energy is the only hope for solving the future energy crisis. Ocean has a vast amount of energy source which can be extracted in variety of ways. Extracting energy from wave is not a new thing. Oscillating Water Column is the most popular among all the used technologies for harvesting ocean energy. OWC can be shoreline, near shore or offshore type. Figure 1 shows simple classical OWC.

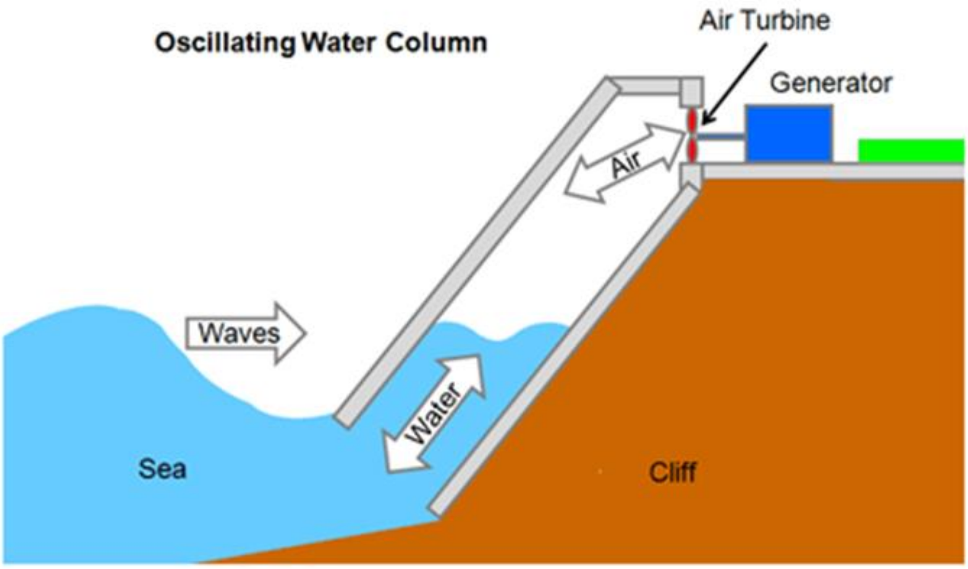

Figure 1. Classical OWC [4]

For WSN and many other on sea projects, offshore OWC can be the most convenient option. And this offshore OWC suffers from the troubles caused by rough sea weather. The idea of closed type OWC discussed in this paper can overcome this difficulty and can proceed the system one step further toward perfection.

2.2. Related Works

Scientists all over the world is trying to make wave energy extraction more easy, cost effective, enduring and most importantly efficient. A study (before 2010) showed that there were over 1000 patented ideas for wave energy conversion. Among different technology groups OWC is a very straightforward device consisting of two basic part: 1) the chamber; and 2) the turbine [5] Multi chamber or segmented OWC has been studied briefly in [6] Performance of the turbines like savonious or wells and effect of guided vanes on wells turbine used in OWC, have also been matter of research. [6,7,8]

2.3. The Closed Type OWC

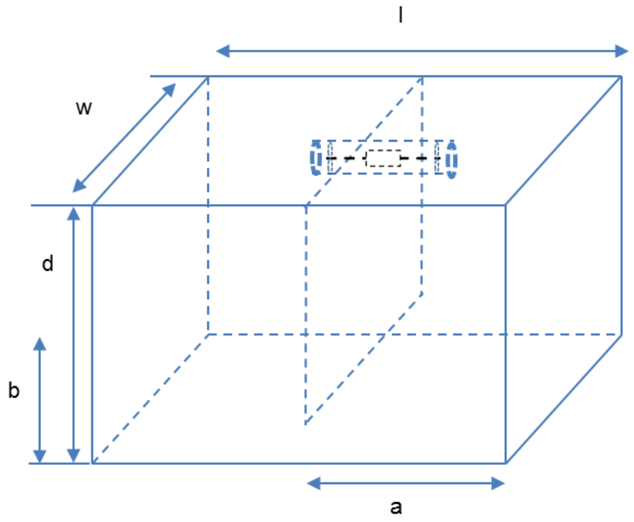

Figure 2. Closed Type OWC Device

An oscillating water column device harnesses the motion of ocean waves as they pressurize a pocket of trapped air. Figure 2 shows an off shore floating OWC device which comprises a partially submerged, rectangular shaped, half water filled chamber with air trapped above the water surface.

In the classical OWC, water waves enter inside the chamber and this water column behaves like a piston, continuously moving up and down that compresses or decompresses the air trapped above the water surface inside the chamber. The compression or decompression of air inside OWC chamber, generate an alternating stream of high-velocity air through a bidirectional air turbine placed in an exit blow hole. This turbine is coupled with a generator to produce electricity [3,9].

The proposed structure of closed OWC utilizes the motion of waves in the sea and works with the same principle of operation as classical OWC except the fact that the sea water waves doesn’t enter or exit the chamber. It works with a fixed amount of water inside the chamber moving from one chamber to other with the ups and downs of the waves of the sea. The air trapped above the water surface moves in the reverse direction with the water, through the two air turbines placed inside a tunnel at the upper portion of the device. The movement of turbine rotor due to the air passing through these, in turn moves the generator which produces electricity.

3. Theory of Operation

The invented structure is a rectangular double chambered vessel with buoyancy material around the down part, floating on water. The two chambers are separated not fully by a barrier which has open portions at the bottom part and at the upright position of the structure. The bottom aperture acts like a channel between the chambers keeping the two chambers in fluid contact with each other. At upper aperture there is a tunnel within which stays two self-rectifying air turbines and a power generator for producing electricity. The whole device is closed type and half filled with water.

On the arrival of water waves, the device gets tilted. The heave motion of the wave that is the ups and downs of the waves causes the water to move from one chamber to other through the down aperture. The amount of water that leaves one chamber, the same amount of water enters another chamber. The rise and fall of water levels in the chambers due to this moving water creates pressure difference in the two chamber which makes an alternating stream of high-velocity air through the upright tunnel. The amount of water moves from *1st* to *2nd* chamber, the same amount of air leaves the *2nd* chamber and enters the first chamber.

As the air moves through the turbine, the turbine goes under movement and rotates a power generator along with it to generate electric power.

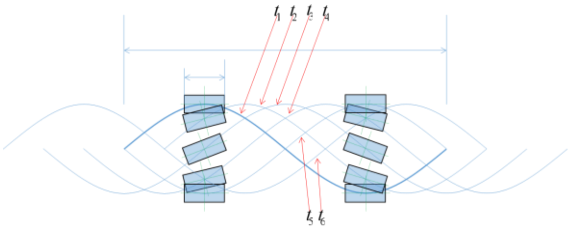

Figure 3. Device Position with Incoming Wave

Figure 3 represents the five different position of the device at five different wave condition in time t1 to t5. From steps 1-5, the device gets tilted in one direction from horizontal equilibrium position and then again returns to the same equilibrium position as before. During this time, water passes from one chamber to another chamber and returns to the first chamber at time t5 through the aperture down the chamber barrier.

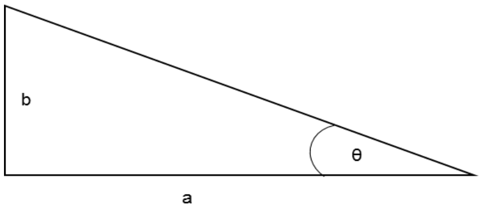

Figure 4. Triangle of Moving Water

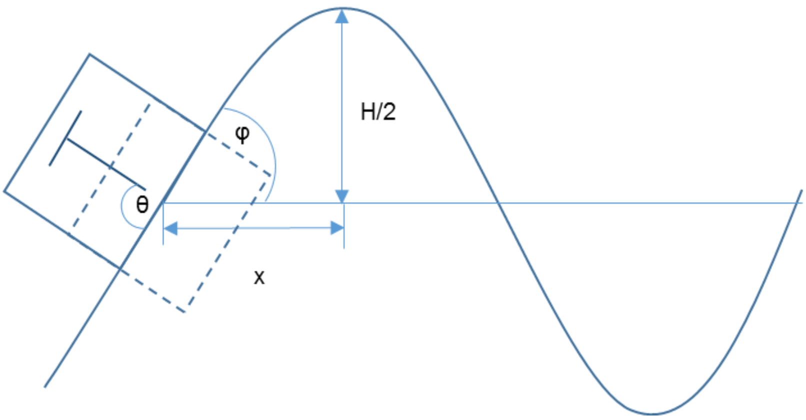

Figure 5. Device at Maximum Titled Position

According to figure 4, let triangle abc amount of water passes once during t_1 to t_3. If the tilt angle is θ, then,

$$\tan\theta(t) = b(t)/a$$
$$b(t) = a\ \tan\theta(t) \qquad (1)$$

Where, $a = l/2$, length of a single chamber
$b(t)$ = instantaneous wave height inside the chamber
$\theta(t)$ =angle of tilt

T = wave period
Φ = inclined angle of wave
d = chamber height
A_1 = area of the triangular portion of water
v_1 = velocity of air just above the water surface
A_2 = area of turbine rotor
v_2 = velocity of wind at the turbine rotor
L = deep water wavelength
x = horizontal distance in time T/4
H = wave height
r_t = radius of the turbine rotor
ρ = air density
From figure 4 and using (1),

$$A_1 = {}^1\!/_2\, ab = {}^1\!/_2\, a^2 \tan\theta = {}^1\!/_2\, a^2 \tan\emptyset \quad \text{[From fig: 4]} \tag{2}$$

According to figure 5, the device gets maximum tilted at time t_3. So,

$$(t_3 - t_1) = {}^T\!/_4 \tag{3}$$

Considering the maximum tilted position of the device, water inside the chamber crosses distance, $b = d/2$, in time $T/4$. So, at $t = T/4$, $b(t) = b$. Then,

$$v_{1max} = \frac{b}{{}^T\!/_4} = \frac{4b}{T} \tag{4}$$

$$v_{1min} = 0 \tag{5}$$

$$v_{1avg} = v_1 = \frac{2b}{T} \tag{6}$$

Again from equation of continuity,

$$A_1 v_1 = A_2 v_2 \tag{7}$$

From figure 5,

$$x = L/4 \tag{8}$$

$$\tan\phi = \frac{{}^H\!/_2}{x} = \frac{2H}{L} \tag{9}$$

So, from (7) wind speed at the rotor,

$$v_2 = {}^{A_1 v_1}\!/_{A_2} \tag{10}$$

$$v_2 = \frac{a^2 H 2b}{LT\pi r_t^{\,2}} = \frac{4a^2 bH}{gT^3 r_t^{\,2}}$$
$$\left[A_1 = {}^1\!/_2\, a^2 \tan\emptyset = \frac{a^2 H}{L} \;\; and\; L = {}^{gT^2}\!/_{2\pi} \right]^{10} \tag{11}$$

Power available from the turbine:

$$P = {}^1\!/_2\, \rho A_2 {v_2}^3 \tag{12}$$

4. Analysis

For a device of length 3m, the length of a single chamber is, a = 1.5m and for chamber height d=1m we get the draft height, b = 0.5m. Taking the parameters into consideration, the graph in fig.6 shows the variation of air velocity obtainable at the turbine, with wave period for three different wave height condition.

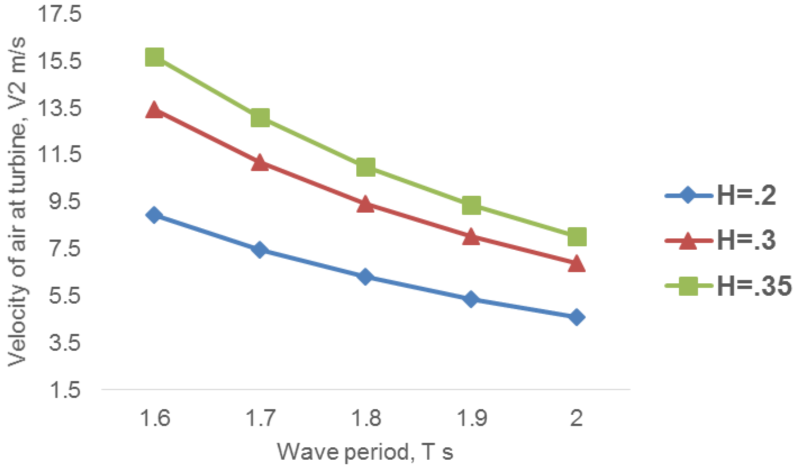

Figure 6. Variation of Air Velocity at Turbine with Wave Period

Using the same parameters and with a turbine of radius 5cm the variation of extractable mechanical power for different outside wave height is given in the table below:

Table 1. Power Available From the Turbine for A=1.5m and B=0.5m

H m	P W at T=1.7s	P W at T=1.8s
0.2	2.009	1.2
0.3	4.055	1.57
0.35	10.77	6.44

Figure 7 shows the variation of extractable mechanical power from turbine, with wave period T.

Calculation was also done to study the effect of device height on power generation. Fig.8 shows the power variation with draft height b.

This is the calculated mechanical power obtainable from the device. Generated electric power will be factor of the efficiency of turbine and generator.

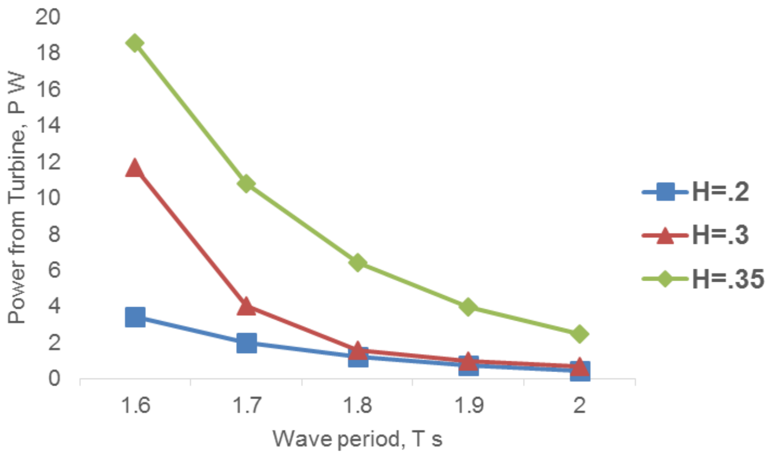

Figure 7. Variation of Power with Wave Period

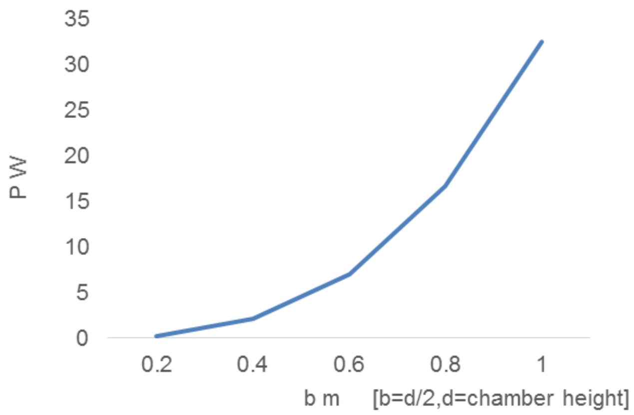

Figure 8. Power Variation with Draft Height

5. Conclusion

From the above analysis, it is clear that both wave height and wave period effects the performance of OWC. For speed of wind at the turbine as well as mechanical power from the turbine, wave height works as a proportionality factor. That is the power from the system increases as the wave height goes high. Again the reverse happens with the wave period. Maximum power can be obtained for waves of minimum period. Device height also plays proportional role on the power production.

The completely closed, floating, offshore, rectangular shaped, double chambered OWC structure which is half filled with water can produce electric power without any interaction with the outside ocean water or atmospheric pressure by using two bidirectional air turbines inside the device. With the system parameters used in this paper, a range of 1-10 W of power, on average can be got from this system depending on different ocean wave condition, enough to meet up the power requirement of the sensor nodes used in Wireless Sensor Network. It's an innovative, simple, stable, cost effective structure with buoyancy material, able to work in the harsh ocean wave climate. As it is completely closed device, it will need less observation and maintenance which is a beneficial characteristic for any off shore on sea floating WEC. The criteria that the lower part of any old boat or ship can be used to build the structure and thus a totally new structure is indeed not a compulsory condition, makes the system more efficient in further ways.

Acknowledgments

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