# A Study on Design and Simulation of the Point Absorber Wave Energy Converter Using Mechanical PTO

Phan Cong Binh

**Abstract -** ***This paper presents a practical design of a wave energy converter (WEC). The WEC is based on an innovative mechanical device power take-off (PTO) which can convert wave energy into electric energy by using a floating buoy. By using cable and pulley mechanism, the WEC can work in high efficiency by capturing wave energy in both surge and heave mode and converting the bidirectional motion of ocean waves into one-way rotation of an electric generator. First, the configuration is presented to describe working principle of the system. Then, the hydrodynamic forces are analyzed in the time domain. Moreover, the coupled mechanical and hydrodynamic model are simulated in Matlab/Simulink to investigate the performance of the proposed design. Finally, simulation results indicate that the proposed WEC can absorb wave energy in high efficiency and can be applied in the realistic condition.***

**Keywords:** ***WEC, Point absorber, Mechanical PTO, Simulation***

## I. INTRODUCTION

Energy in general and electric power in particular are essential for human life and production. This also means that when people's living standards and production demands are increased, the demand for electrical energy also increases. This is a big challenge for most countries, including Vietnam.

Compared with other renewable energy sources, wave energy has less investment, greater safety, greater social consensus, requires no large and complex operating systems and the level of environmental impact is not high. However, among the renewable energy sources being researched and exploited in Vietnam, wave energy has not received much research attention and exploitation, although, it is known that the conversion efficiency into the electrical energy of this power source is quite high.

Electric energy form waves have been tested for many years but it has no desirable results. Today, when science and technology is developing and the world is facing serious consequences due to climate change, scientists believe that it is possible to transfer the wave energy into the electric power through the power adapter

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The global energy crisis of the 1970s prompted research to use renewable energy sources. Research on ocean wave recovery has always been the subject of the greatest number of works due to the stability of the ocean energy and high energy density. According to statistics in the world, there are hundreds of companies running in this field. In addition, many organizations and individuals contribute a lot of works from inventions and innovations to constantly research and develop WEC devices and technology.

After studying various devices of wave energy convert, the float wave energy convert (WEC) model is best suited because of ease of fabrication and in accordance with research conditions. Compared to others, WEC is easy to install, repair and maintain because of the components and generators located on land; The cost of installation, operation is less expensive, suitable to the conditions in coastal areas, islands ...

This article analyzes a creative wave energy conversion design. Here, a bidirectional gearbox (BG) is used to convert wave motion into electricity through a floating buoy. In this study, the specification of the PTO mechanism and the working principle is showed clearly. The floating buoy which is connected to a bidirectional gearbox (BG) and torque generation device is simulated in Matlab/Simulink in the mechanical and hydrodynamic time domain. The hydrodynamic forces acting at the float buoy are calculated by using the linear potential wave theory. The simulation results show that there a good agreement with experimental results of others.

## II. CONCEPTUAL DESIGN PRINCIPLES

The configuration of the given WEC is shown in Fig. 1. It includes: 1. Buoy, 2. Cable, 3. Drive pulley, 4. Chain gear, 5. One-way gear box, 6. Basic. 7. Balance – weight, 8. Generator, 9. Flywheel.

When the wave acts at the floating buoy, it moves up and down due to due to hydrodynamic and gravity forces. The movement of the floating buoy through the drive pulley will cause the chain drive to rotate. This makes the main shaft of the two pinions are joyed to two main shafts linked to gears by one-way bearings. So, the up and down motion of the floating buoy will create one-way rotation of the output shaft. And the flywheel and the generator shaft also rotate. The flywheel will stabilize the speed of the generator. Balance - weight will help maintain the up and down movement of the float buoy. The electric generator is fixed

and driven by the output shaft. It will generate the electricity and create the light for the light bulbs.

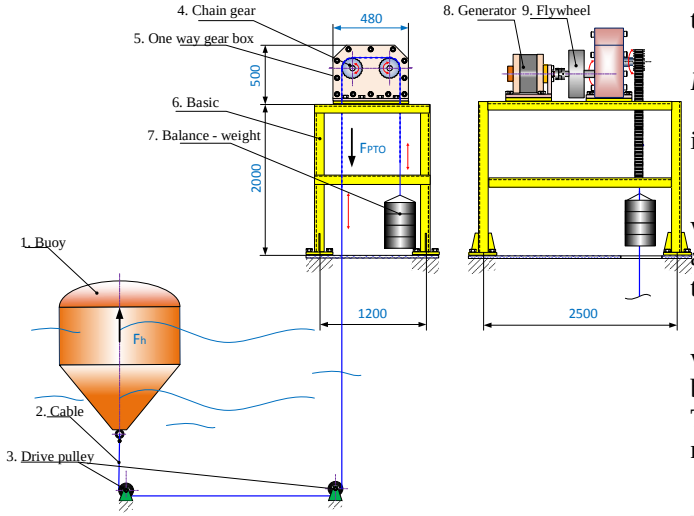



Fig 1. *Configuration of WEC*

## III. MATLAB/SIMULINK MODEL

### *A. Modeling of wave energy converter*

The floating buoy dynamic model of the WEC is shown in figure 2.

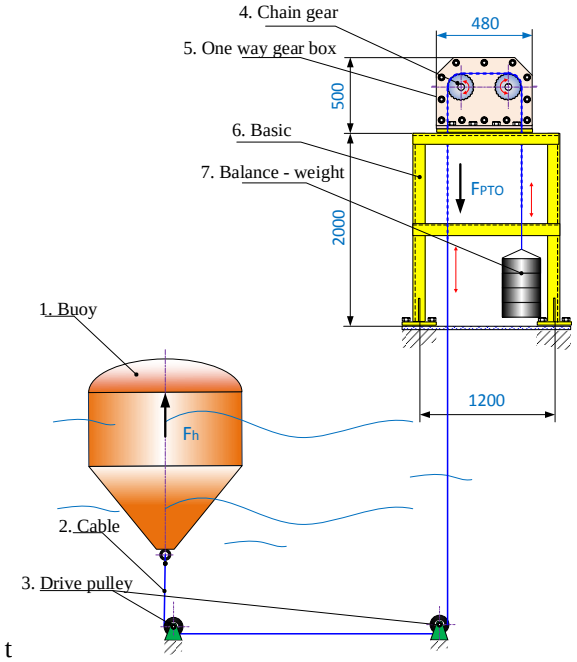



Fig 2. *The floating buoy dynamic model of the WEC*

For harmonic waves, we have the equation of the wave elevation is:

$$\eta = A\sin\omega t \ (1)$$

In this paper, the movements of the floating buoys can be modeled in time domain by solving the appropriate differential equations. Invoking Newton's second law, the total force acting on the buoy comprise the hydrodynamic force $F_h(t)$ because of incoming waves and the resistive force $F_{pto}(t)$ due to the load resistance of the PTO system:

$$M_b\ddot{z}(t) = F_h(t) + F_{pto}(t) \ (2)$$

where $M_b$ is the mass of the buoy and z is the elevation of the floating buoy.

### *B. Hydrodynamic model*

The hydrodynamic force acting on the buoy is presented in the following equation

$$F_h = F_e + F_r + F_s \ (3)$$

where $F_e$ is the excitation force which is a function of the amplitude, frequency and phase of waves, and it is given in the following equation:

$$F_e = f_3 A\sin(\omega t + \alpha) \ (4)$$

where $f_3$ is the force amplitude, and α is the phase difference between the wave and the excitation force.

The radiation force caused by buoy oscillations is required to move the buoy, and it is present in Eq. (5)

$$F_r = -M_a\ddot{z} - R_r\dot{z} \ (5)$$

where $M_a$ is the added mass at an infinite frequency, and $R_r$ is the radiation damping coefficient.

The hydrostatic restoring force, due to excursion of the buoy from its equilibrium position, can be calculated by using the Archimedes principle, and it is simply given in Eq. (6):

$$F_s = -S_b z \ (6)$$

where $S_b$ is the hydrostatic stiffness.

The user's force reacting to the PTO is the required force to drive the PTO system. It is usually calculated as follow:

$$F_u = -F_{pto} = -\frac{T_0}{r_0} = -\frac{i_{pto}T_g}{r_0} = -\frac{i_{pto}R_u\omega_2}{r_0} = -\frac{i_{pto}^{\ 2}}{r_0^{\ 2}}R_u\dot{z} \ (7)$$

$$F_u = -R_{pto}\dot{z} \ (8)$$

where $T_0$ is input torque of gear box, $T_g$ is output torque of generator, $R_u$ is user's coefficient, $i_{pto}$ is the ratio of the PTO mechanism, $r_0$ is radius of the pinion of the sprocket.

By substituting Eq. (4)~(8) in Eq. (2), it is given in Eq. (8):

$$(M_a + M_b)\ddot{z} + (R_r + R_{pto})\dot{z} + S_b z = f_3 A\sin(\omega t + \alpha) \ (9)$$

Invoking Archimedes law, $M_b$ is the volume of water occupied by floating buoy at the free water surface.

One wave region has the initial wave parameters as shown in the following table.

TABLE 1. INITIAL WAVE PARAMETERS

| Specifications | Parameters |
|---|---|
| Wave height H (m) | 0.08 |
| Wave amplitude A (m) | 0.04 |
| Wave period T (s) | 2 |
| Wave length λ (m) | 6.24 |
| Wave number k (rad/m) | 1.0064 |
| Angular frequency ω (rad/s) | 2.873 |
| Water depth h (m) | 2 |
| Water density ρ (kg/m$^3$) | 1020 |

Basing on Fig. 4 [2], ω=2.873rad/s, α= $8^0$, $f_3$=3500N/m, $R_r$ =225Ns/m, $M_a$=162kg.

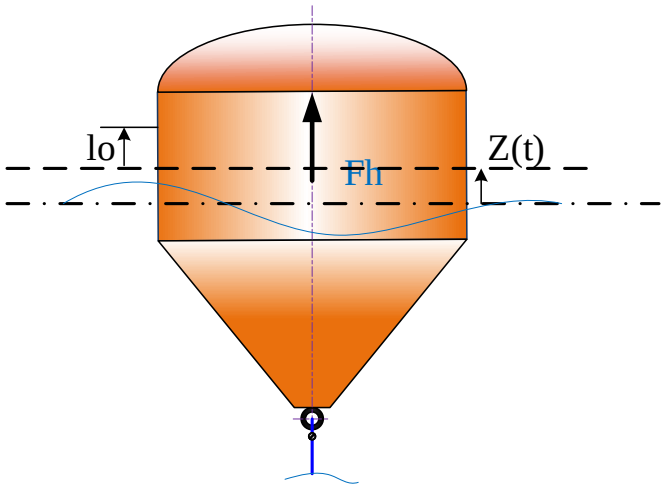



Fig 3. *Configuration of floating buoy*

$S_b$ is the hydrostatic stiffness and presented in [1]

$S_b = \pi\rho g r^2$ =3.14x1020x9.81x0.6$^2$=11311 (N/m)

*C. Simulation process of displacement of the wave and the*

Some initial parameters of the working conditions are showed in table 1.

TABLE 2. SETTING WORKING CONDITION FOR SIMULATION

| Specifications | Parameters |
|---|---|
| Wave height H (m) | 0.08 |
| Wave amplitude A (m) | 0.04 |
| Wave period T (s) | 2 |
| Wave length λ (m) | 6.24 |
| Wave number k (rad/m) | 1.0064 |
| Angular frequency ω (rad/s) | 2.873 |
| Water depth h (m) | 2 |
| Water density ρ (kg/m$^3$) | 1020 |
| Added mass $M_a$ (kg) | 162 |
| Buoy mass $M_b$ (kg) | 1000 |
| Excitation force $f_3$ (N/m) | 3500 |
| Phase angle α (deg.) | 8 |
| Hydrostatic stiffness $S_b$ (N/m) | 11311 |
| Radiation damping coefficient $R_r$ (Ns/m) | 225 |
| User's coefficient $R_u$ | 0.1;0.125 |
| Gearbox ratio $i_{pto}$ | 8 |
| Floating buoy radius a (m) | 0.6 |

Using MATLAB/SIMULINK to simulate the motion of the wave the buoy

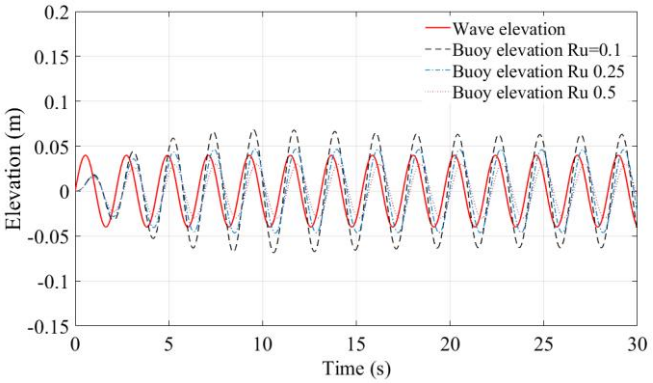



Fig 4. *Simulation result of wave and buoy elevation*

*D. Energy conversion efficiency*

To investigate the harvested energy efficiency of the proposed WEC, the average wave power and absorption power must be predicted by using the linear potential wave theory [1]. The power going to the generator is also obtained by using the measured values from the torque transducer. For the constant depth water h, the width capture and average wave power is given by the set of equations (10)

$$P_1 = Ec_g \quad (10)$$

$$E_1 = E_k + E_p = \frac{1}{8}\rho g^2 H^2 \ (\mathrm{J/m^2}) \quad (11)$$

where $E_1$ is the mean wave energy density per horizontal unit area, and equals the sum of kinetic $E_k$ and potential energy $E_p$; $c_g$ is the group velocity, which can be obtained for constant water depth h, in the set of equations (12)

$$c_g = \frac{D(kh)}{2\tanh(kh)} c_p = \frac{g}{2\omega} D(kh) \quad (12)$$

$$D(kh) = [1 + \frac{2kh}{\sinh(2kh)}]\tanh(kh) \quad (13)$$

where *D(kh)* is the depth function; *k* is the angular repetency (wave number). Wave energy is written: $E_1 = \int P_1 dt$ (14)

The output power of the generator is defined as Ed. (14)

$$P_2 = T_0\omega_2 = R_u\omega_2^2 = R_u(i_{pto}\frac{v_1}{r_0})^2 = \frac{R_u i_{pto}^2}{r_0^2}\dot{z}^2 \quad (15)$$

And generator energy is written $E_2 = \int P_2 dt$ (16)

*E. Simulation process of energy conversion efficiency*

TABLE 3. SETTING WORKING CONDITION FOR SIMULATION

| Specifications | Parameters |
|---|---|
| User's coefficient $R_u$ | 0.1; 0.15 |
| Ratio $i_{pto}$ | 8 |
| Radius $r_0$ (m) | 0.02 |

Basing on the Eq. (11) ~ (16), we use Matlab/Simulink to simulate energy of the wave and the generator.

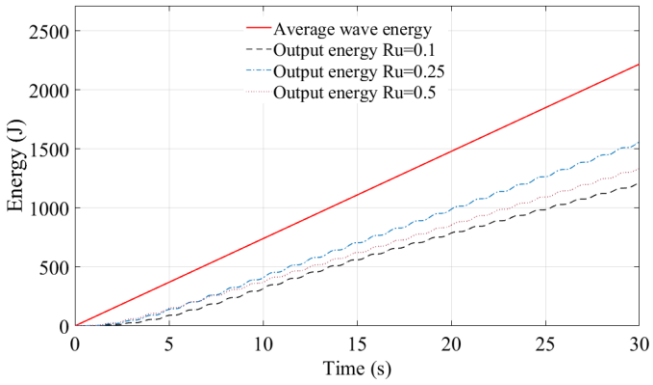



Fig 5. *Simulation energy of wave and buoy*

## IV. DISCUSSION

Figure 4 shows that the floating buoy movement depends on the user's coefficient $R_u$. When $R_u$ increases, the amplitude of the floating buoy decreases. Because $R_u$ is representative for the damping coefficient, it is inversely proportional the buoy amplitude.

Figure 5 shows the output energy which obtained during the 30 second period. When the $R_u$ value is large or small, the energy is not high. Energy is only high at some optimized $R_u$ values. Here, $R_u$ = 0.25 the output energy is higher compare to that of $R_u$ = 0.1 or 0.5.

In summary, the harvested energy strongly depends on $R_u$ value but not buoy amplitude.

## V. CONCLUSION

This study contributes an improved WEC design. Conceptual design and working principle are introduced in detail. Mathematical model is analyzed by applying linear wave theory. The simulation result shows that displacement and the output energy is suitable with previous works. The performance of the design is relatively high and can be apply to realistic condition.

In the future, it can be studied to optimize the parameters of device to maximize the harvested energy.

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