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Evaluation of Methods to Enhance the Ocean Wave Energy Convertor Performance

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ABSTRACT

Ocean energy represented by waves is considered as a one of the renewable energy sources. This study aims to evaluate the methods that enhancing the ocean wave energy convertor performance. The mechanism of wave energy convertor is by converting mechanical energy to an electricity energy using DC generator and running by the pulling of wire due to ocean wave movement. Moreover, the test and analyze of converting the wave energy to electricity are conducted. Firstly, the role of numerical modelling lies in fabricating the tested rig in addition to study and analyze the buoyancy and stability in fluid mechanics as results of converting the kinetic energy derived from sea waves into rotational energy. The experimental tests were achieved locally at the Arabic gulf-South of Iraq/Basra (Khor Alzubayr). the tests were performed in two cases named: after happening the tidal (tested in one direction) and at the increasing of the sea water (tested in bidirectional). The results of local tests (at the sea) show that the maximum power of test was recorded value about 68 W in case of happening the tidal with an increase percentage of 92.6% over the case of bidirectional. These findings encouraging for more investigation in the methods that could increase energy harvesting from ocean waves since it is an enormous amount of energy.

1. Introduction

The rise in interest in renewable energy sources has been attributed to various factors such as the escalating cost of refining fossil fuels, concerns over their eventual depletion, greenhouse gas emissions, and their negative impact on the climate. Additionally, environmental pollution associated with non-renewable energy sources has contributed to the need for alternative energy sources. Consequently, researchers globally are actively seeking solutions to reduce our dependence on non-renewable fossil fuels and transition to sustainable energy alternatives [1-3].

Researchers are conducting studies on wave energy as a form of renewable energy source. The constancy and relative predictability of sea waves provide an advantage over other renewable sources such as solar and wind. While, there may be slight variations in resources during different seasons, the consistency of resources on a daily basis remains generally stable at specific locations [4].

Ongoing research is focused on advancing more efficient and reliable designs, given that

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wave energy converter technology is still in its early stages of development. Continuous development of new devices is driven by the fact that no single type has proven to be superior in terms of effectiveness, production cost, and maintenance requirements.

In order to effectively harness oceanic sustainable energy, such as wave energy, a comprehensive understand of the available resources and oceanographic circumstances in the target area is necessary [5, 6].

The design of a wave energy harvester must take into account the specific installation site. If the system is not constructed to withstand the observed wave conditions, its efficacy may be compromised and its functionality may vary in other locations with different wave patterns. When it comes to offshore wave energy extraction systems, multipart wave phenomena including radiation and diffusion as well as nonlinear oscillations are a part of the hydrodynamic and mechanical process that goes into the process. Primary Interface (PI) and Power Take off (PTO) are the two main components of a standard Wave Energy Converter (WEC). The portion of the WEC known as the PI is in charge of capturing wave energy and converting it into mechanical energy (such as the reciprocating or rotating motion of a shaft). the PTO is responsible for the conversion of mechanical energy into a more easily transmissible form of energy, which is typically, though not exclusively, electrical energy [4, 7].

The main types of PTO machinery are shown in Figure 1 and their efficiencies is shown in Table 1 respectively.

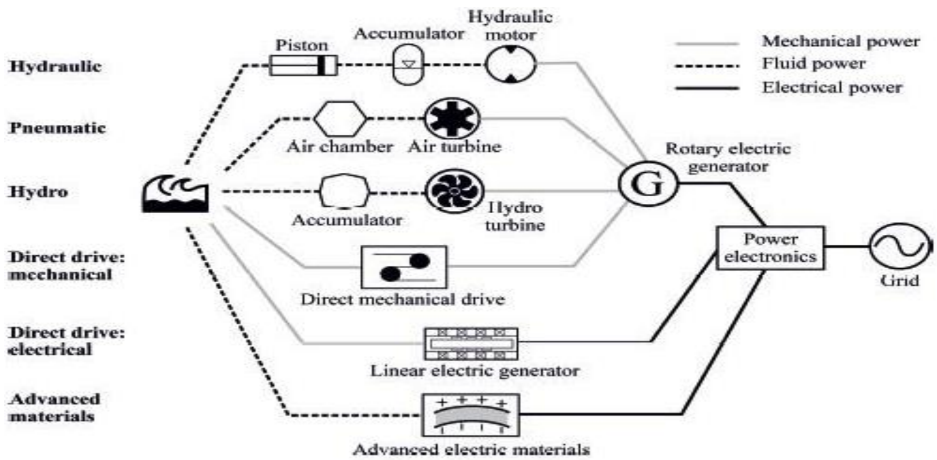

Figure 1. Power take-off principles utilised for the wave energy conversion[8]

Table 1: Indicative efficiency of different PTO systems[9]

PTO system	Efficiency, %
Hydraulic	65
Pneumatic	55
Hydro	85
Direct mechanical drive	90
Direct electrical drive	95
Advanced electric materials	< 80

(Bosma, 2013) indicated that an in-depth understanding of the available resources and oceanographic conditions in the area evaluated for energy harvesting is necessary to harvest marine renewable energy, such as wave energy. Additionally, it is essential to consider the installation site when designing a wave energy harvester, making it crucial to construct a system capable of handling the waves present at the intended location [10].

(Guo & Ringwood, 2021) As for ocean wave power systems, wave power generation processes involve challenging hydrodynamic and mechanical interactions characterized by complex wave phenomena such as radiation, diffraction, and nonlinear oscillations. The PTO transform the mechanical energy produced into an energy type that can be transmitted more easily typically, but not always, electrical energy [11].

(Zhu, Hu, Sueyoshi, Yoshida, & Technology, 2020) reported that the Wave Energy Converters (WECs) are devices that transform wave energy into electrical current. Around 16 MW of operational wave power were installed globally in 2020, which is roughly 5 orders of magnitude less than the 2-3 TW needed to fully utilize the world's wave energy potential. The production costs per unit of electricity generated, which were approximately ten times greater in 2020 than those of offshore wind farms, represent a noteworthy variable [12].

In recent years, a considerable number of patents have been granted due to the numerous innovative methods for harnessing wave power that have emerged in the last thirty years. Globally, both commercial and academic sectors are exploring diverse concepts for wave energy conversion. This study effort is fundamentally at the methodical optimization of WEC performance for the three-energy transmission stages:

Wave energy conversion into mechanical energy by wave structure interaction between device structures and ocean waves

Transferring mechanical rotation energy into an electrical power (through a direct drive generator, or indirectly via for example; rotation motion by wind turbines, mechanical rectifiers motion or gearboxes) using optimal control strategies for tune system dynamics to maximize power output.

lower electronics to improve power quality into transfer non-standard AC power to direct current power for energy storage or standard AC power for grid integration [13, 14].

This study aims to evaluate the methods to enhance the ocean wave energy convertor Performance. There are two approaches suggested in this experiment to evaluate the wave energy can be harvested. The first method is using raft floated on the water surface with a gear to increase the speed of rotation in account of the amount of power, and to control the rotational direction and speed of the generator, which is in one direction with the rise of the sea wave. The second approach is implemented by setting role with spring to make rope harvesting energy in both directions of water surface movement during the tidal.

2. Theoretical and methodology

bouncy force and the transferring to energy method is the main factor to calculate the energy amount. Moreover, the bouncy force that can carry large ships in the sea is enormous energy and it could be used to generate electricity. In addition, according to the first law of thermodynamics which is says “the energy can’t be destroyed or created but transferring from form to other”. Therefore, this huge energy can be used without violating the first or second law of thermodynamics. Further, the mechanism depended in this theory to design the energy transfer from shape to another as will be shown later.

2.1 Buoyancy force

The main concept of floating or sinking is the difference between the water density and the object the putted in it. In other words, ships floating in the sea because the average density of it is lower the water density. Therefore, the following equations show the bouncy force and the relation to power amount.

$$F_B = W = 294.3N \quad (1)$$

$$\rho_{body} = \frac{W}{g\, V_{sub}} = \frac{294.3}{0.114 \times 9.81} = 263\,\frac{kg}{m^3} \quad (2)$$

$$V_{dis} = \frac{F_b}{\rho_{f \times g}} = \frac{294.3}{1025 \times 9.81} = 0.0292 m^3 \quad (3)$$

$H_{dis} = 3.072$ cm

$CB = 1.536$ cm

$CG = 6$ cm

$$CG_{final} = \frac{W_n \times CG}{W_t} = 9.8 \text{ cm} \quad (4)$$

$I_o = \frac{\pi d^4}{64} = 0.07186\ m^4$ (5)

$\frac{I_o}{v_{dis}} = 2.52$ m

$GM = 2.52 - 0.0826 = +2.4$ m (6)

Metacenter is plus then raft is stable.

Where :
F_B is the buoyancy force
W is the weight body
V_{dis} is the volume of displaced fluid
H_{dis} is the high of displaced in fluid
CB is the center buoyancy
CG is the center gravity
W_n is the new weight
W_t is the total weight
I_o is the Moment of inertia about a point
GM is the distance for metacenter

2.2 Pulleys and Belts

Belts and pulleys are used to transfer the rotation of one shaft to another. In essence, pulleys are toothless gears that rely on frictional forces to connect belts, chains, ropes, the speeds of the pulleys are inversely proportional to their diameters, just like with gears. spin at the same speed if their diameters are the same, they will rotate at the same speed. However, a mechanical advantage and raised velocity ratio are obtained if one of the two pulleys is larger than the other. The speeds of the pulleys are inversely proportional to their diameters, just like with gears.[11].

General, drives are more desirable than other power transmission mechanisms such as gears and chain drives due to their presence [15]:

- Capacity to absorb power variabilities, shocks, and overloads: Belt drives utilize friction to sustain connection between the driver and follower pulleys. Therefore, when subjected to shocks or overloading, the belt and pulley surfaces can slide against each other as a means of dissipating the forces. This prevents excessively high torques from being transmitted for driven parts, preventing damage to the machine.
- Capability to change velocity and torque: Speed and torque can be varied by changing the diameters of the pulleys as shown in Figure (1). Similar to gears and chain drives, belt drives produce mechanical advantage expressed by:

$$MA = \frac{\tau b}{\tau a} = \frac{rb}{ra} = \frac{\omega b}{\omega a} \quad (7)$$

Where:
MA is the mechanical advantage,
τb and τa are the torques
rb and ra are the radii of the pulleys
ωa and ωb are the angular speeds.
These equations are true in an ideal scenario where there is no power loss between pulleys.

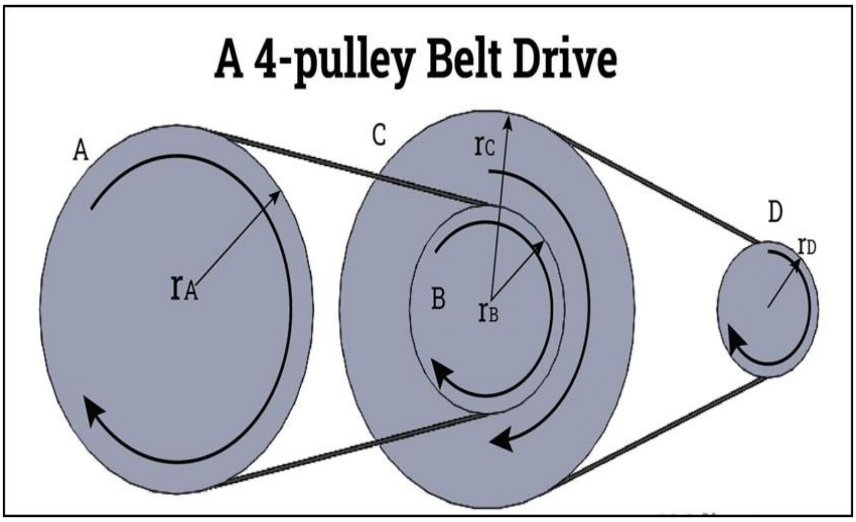

Figure 2. Motorized drive roller belts for increase speed[16]

2.3 Sprockets and Chains

Moving belt friction wouldn't be sufficient for power transmission, chains and sprockets offer an alternative method of transmitting rotary motion from one shaft to another. As shown in Figure 2, the speed relationships between pulleys of various diameters paired with belts are identical to those between sprockets of various diameters coupled with chains. As aresult, if the chains are crossed, the sprockets will rotate in different directions. The bicycles have chain and sprocket drives. The links on the chains and the teeth on the sprockets mesh.[15, 17].

2.4 Description of WEC

Generally, the wave energy converter (WEC) is consisted from five main components as shown in Figure 3. Most of these components were fabricated and fashioned from locally-sourced equipment. These components named as: Raft, generator, gear assembly, main pulley and torque limiter.

The working mechanism of the Main Pulley and spring is that during the rise of the wave will lead to the lift of the device, then it pulls the wire down to move the transmission wave to the gearbox, then the movement transmits for alternator to generate electrical energy. When the wave descends, the wire must return to its normal position, the spring used for this purpose. The spring is a tensile force that works to pull the wire and return it to its normal position before the rise of the wave.

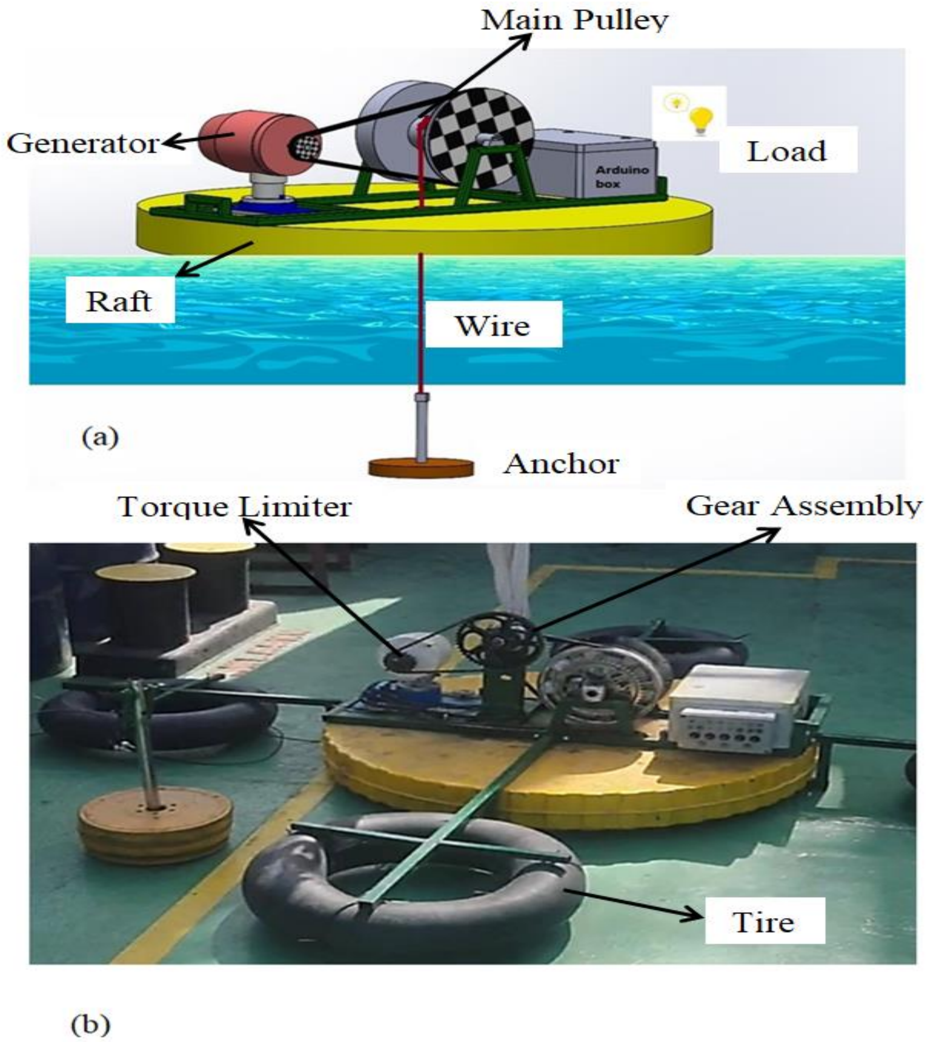

Figure 3. The proposed system (a) Diagram of system (b) Photograph of system

3. Results and discussion

In this section, the experimental tests were achieved locally at the Arabic gulf-South of Iraq/Basra (Khor Alzubayr) in two stages. The local tests were performed in two cases named: after happening the tidal (tested in one direction) and at the increasing of the sea water (tested in bidirectional). As shown in Figure 4, the maximum voltage was recorded 23 V and 4.8 V in case of after tidal one directional test and bidirectional test respectively. This can be summarized as the one direction in case of after tidal test can achieve an increase of maximum percentage about 79.1% over the bidirectional test.

The same case applies to the values of current and power in one direction, as the values of the increase in them were recorded a maximum percentage about 49% and 95.5% respectively more than the bidirectional method as shown in Figure 5 and 6.

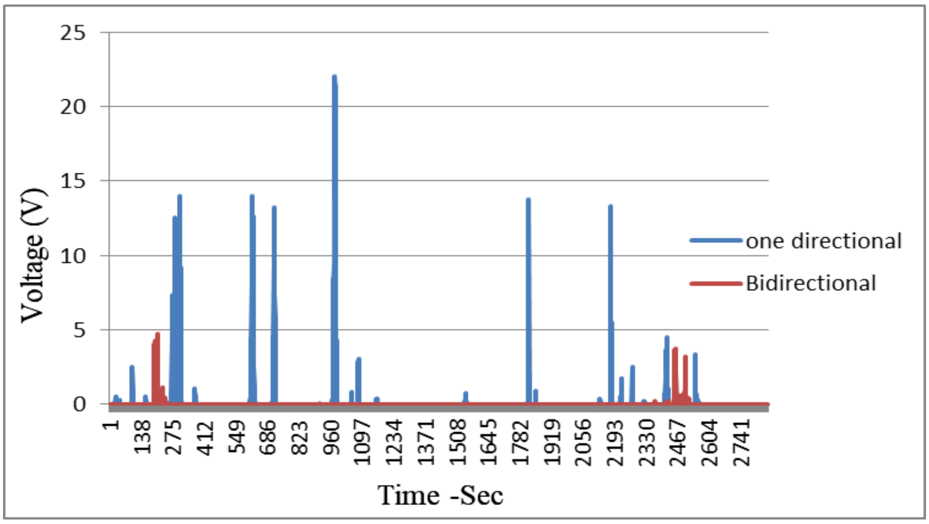

Figure 4. Generated voltage during (one directional and bidirectional) tests

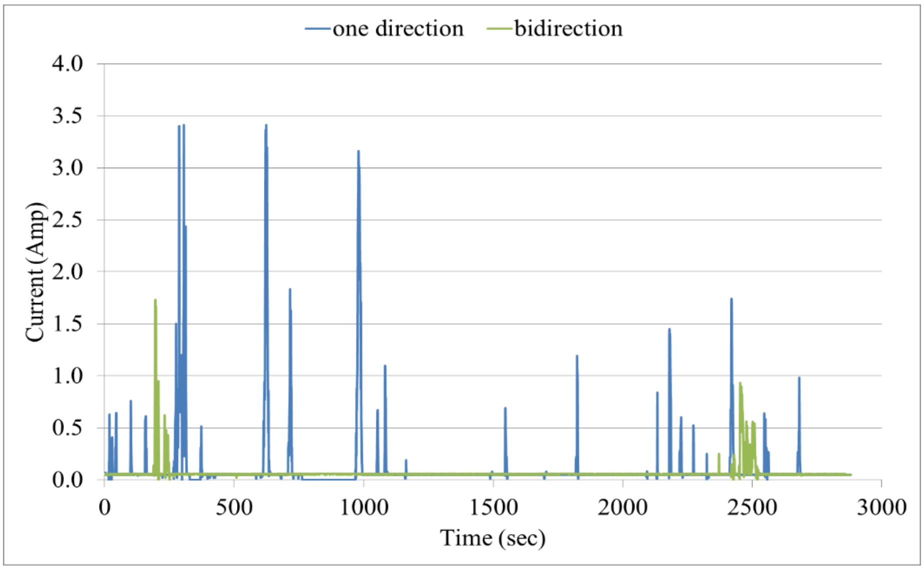

Figure 5. Generated current during (one directional and bidirectional) tests

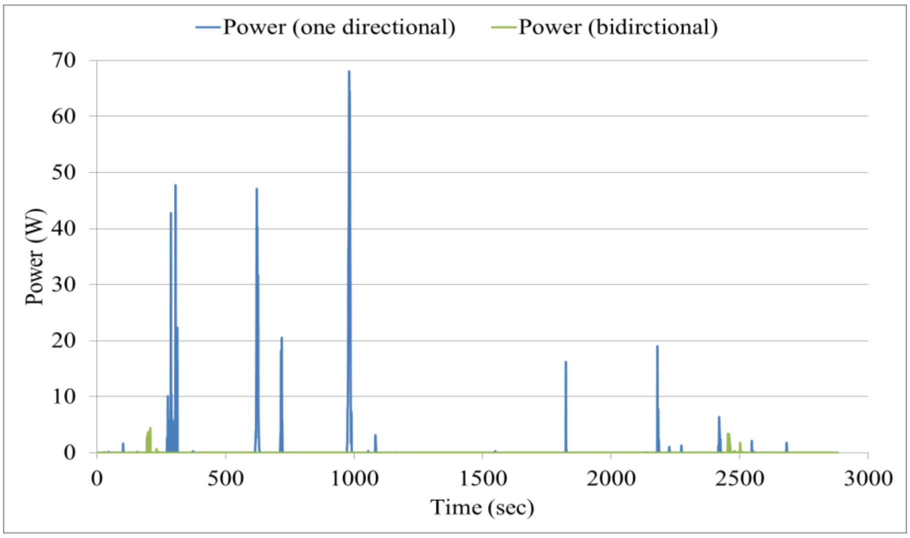

Figure 6. Generated power during (one directional and bidirectional) tests

The electric energy generated during the experiments was collected and registered. Each test period was about 50 minutes during the both set of design (for one direction and bi directional). Further, the amount of energy harvested during the one-direction test was much larger than the bidirectional operation method. Moreover, the quantity of electrical power stored during the bidirectional test was the smallest which is about 50 Joule or 0.01 W.h. However, the electrical energy gathered in one directional was about 1200 joule (0.3 W.h) as presented in Figures 7 and 8. These results proved that there is a chance for using wave's energy. However, this electrical energy is not steady or consistent. Therefore, it is very advised to use battery that can be charged through the electrical generation to maintain a firm electric energy that could power different applications. In according to these outcomes, the results show very hopeful findings. Where, the electric generating during tidal was much more the opportunity of generating electricity at other times. Finally, the energy reached about 1200 Joule at accumulated time (50 minutes) when the tidal is available.

In contrast, it is reached about 50 Joule at the same time when the generator is running in bidirectional.

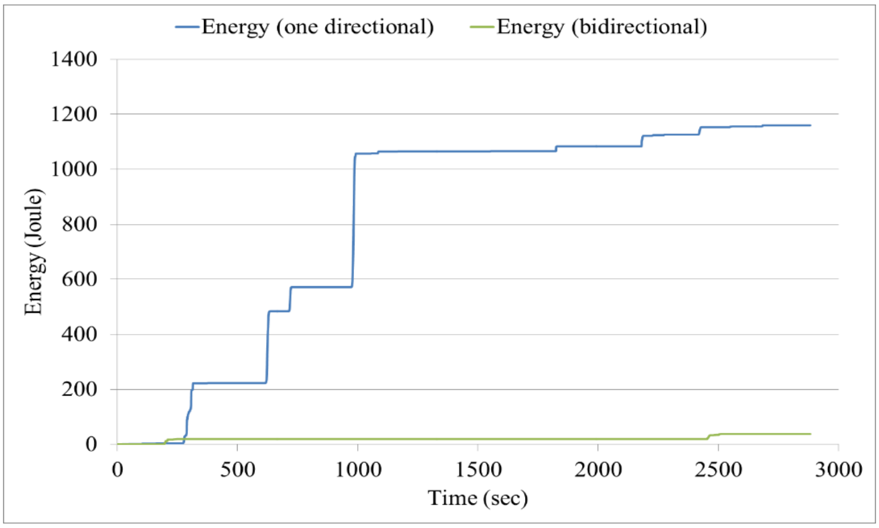

Figure 8. The accumulated energy harvested during (one directional and bidirectional) tests

Figure 9 shows the average generated power during the local tests. The largest value of average power was recorded about 0.44 W in case of after tidal test. While, the smallest amount of average power was recorded about 0.01 W at the case of bidirectional test. Figure 10 shows the normal energy generated during the local tests. The maximum value of average energy was recorded 1590.99 W.h in case of after tidal test. Likewise, the smallest value of average energy was recorded 50 W.h at the bidirectional test. The relatively weakness of the roller spring that control the pulling of the wire after rising or falling of the waves is controlled the weak generated energy from. The main reason that controlled the energy power generated in bi-directional case is the relatively weakness of the roller spring that would tug the wire after rising or falling of the waves. In other words, the spring was not able to make the generator for generating and pulling the wire at the same time. However, in one direction, the spring of roller is able to pull the wire after wave passing quicker which make the raft ready for the next wave.

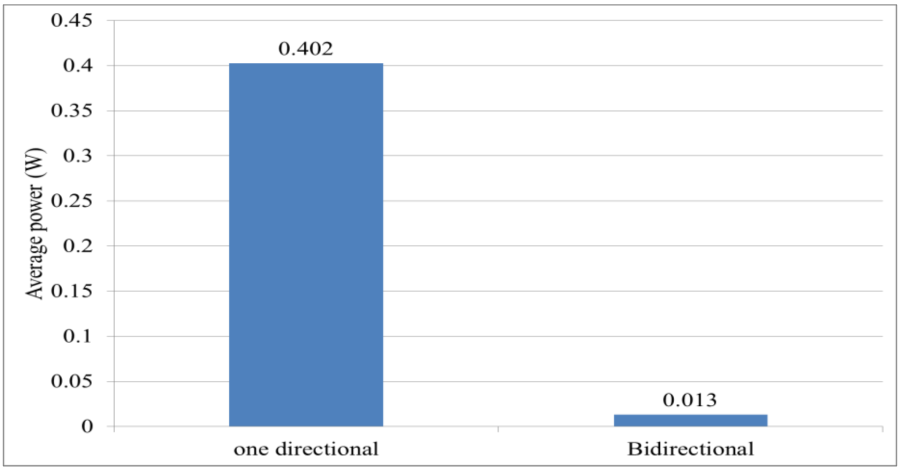

Figure 9. The average power generated during the test of (one directional and bidirection)

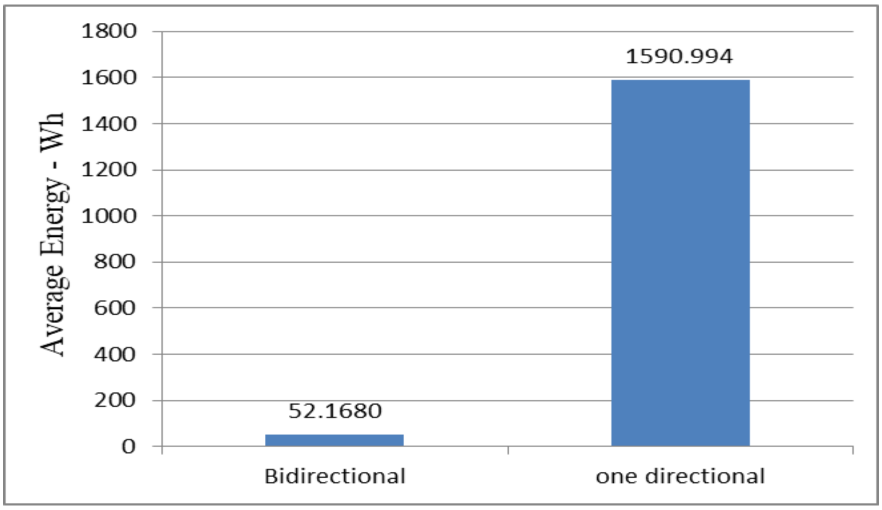

Figure 10. The average energy generated during the test of (one directional and bidirection)

4. Conclusions

This study presents an experimental investigation to test and analyze of converting the wave energy to electricity. Firstly, the role of numerical modeling lies in fabricating the tested rig in addition to study and analyze the buoyancy and stability in fluid mechanics as results of converting the kinetic energy derived from sea waves into rotational energy.

According to the obtained results, the following conclusions are summarized as:

1. The proposed WEC is simple and easy for fabricate from available materials and maintain.
2. To harness wave energy, linear heave oscillation of the raft is converted into a rotary motion through the design.
3. The results of the laboratory tests show that the maximum electrical power is produced in one direction with a value of power about 85 W with an increase percentage of 79.5% over the case of bidirectional.
4. Experimental investigations carried out on the scaled model of the raft show the following observation namely power absorbed by the raft increased with wave height.
5. The electrical generating during tidal was much more the chance of generating electricity at other times.
6. During the tidal, the energy reached about 1200 Joule at accumulated time (50 minutes). In contrast, it is reached about 50 Joule with the same time through the test bidirectional.
7. The results of local tests (at the sea) show that the maximum power of test was recorded value about 68 W in case of happening the tidal with an increase percentage of 75% over the case of 92.6% over the case of bidirectional

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