Design and analysis a new converter for extraction of low-height wave energy in Persian Gulf

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Abstract

Low-amplitude waves in the Persian Gulf are due to the short length of fetch in the sea, geographical conditions, and the seabed topography. In the Persian Gulf, the wind direction and wind speed changes are uniform during the year due to latitude and longitude of the Persian Gulf and little variation in its climate and the consistent climate in Gulf-around. The small changes of wind speed and its direction give rise to form waves with little changes in the frequency. In this paper, the point absorber wave energy converters were evaluated from different point of views. Applying some changes on the geometry of energy absorber buoy, wave energy conversion and storage system, its algorithm, and mooring system of conventional devices of point-absorber converters, a new converter was designed for energy absorption of short-amplitude waves (less than one meter) in the Persian Gulf. Furthermore, cylindrical buoy in Cosine curve form was designed and the extracted energy was compared with a study by Pastor and Liu in 2014 on the absorbed energy by different buoys. A hydrodynamic analysis was carried out on a converter with a tension leg mooring and the results were compared with the results of a study by Yu and Li in 2013, which was based on the dimensions of the point-absorber converter, OPT-PB150. The results showed that applying variations in the performance of conventional devices and using of tension leg mooring, enables the extraction of short wave energy in the Persian Gulf.

Keywords: Heave resonance; Persian Gulf; Hydraulic circuit system; Tension leg mooring, Point absorber converter.

1. Introduction

The existence of small islands in the Persian Gulf and away from the Iranian plateau with seasonal power shortages and occasionally electricity outages raises the importance of designing a wave energy converter to make electricity for Iran's strategic Islands. Based on a research by Shafaghat *et al.*

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(2014) about wave energy harvesting technologies consistent with climate conditions and the specifications of governing waves in Iran waters, the converters point absorber has been suggested as the best option. Today, parts of the electricity consumed in Madeira Island in Portugal and Creek Islands are funded by the point absorber wave energy converter (Aquabuoy) and two point absorber converters; OPT, and SEAREV are being exploited in the Azores Island in Portugal and the Ireland, respectively.

In fact, different researches have been conducted in point absorber converter. Koh *et al.* (2014) conducted the estimating of effects of resonance on the absorbent buoys. Furthermore, Pastor and Liu (2014) represented different buoys affection on the amount of wave energy absorption, and Li *et al.*, in 2013 from American National Center of Renewable Energy, investigated the point absorber wave energy converter based on the OPT-PB150 model dimensions (Yu and Li, 2014). In this paper, these researches are considered in designing a converter to absorb the energy of the waves with short amplitude (less than one meter) in the Persian Gulf.

2. Materials and methods

2.1. Wave energy

The interaction between wind and sea level generates waves, and the wave characteristics depend on the wind speed, wind duration, and the fetch. The wave has two types of energy, one due to wave amplitude changes, and the other kinetic energy of water particles in the wave rings (Antonio and Falcao, 2010). Figure 1 shows the wave production process. The Equation (1) calculates the wave energy, which λ is wavelength, H is wave height, ρ water density, and g is Gravity.

$$E = \frac{\rho g}{8} H^2 \lambda \quad (J/m) \quad , \quad \rho = 1025 kg \tag{1}$$

The stations for waves' characteristics measurement, usually record wave significant height (H_s) and peak of wave period (T_p) in defined time range, and accordingly, the wave power (P) in deep water can be approximated by Equation (2).

$$P = \frac{\rho g^2}{4\pi} T_e \; H_s (W/m) \quad , \quad T_e = \alpha T_p \tag{2}$$

which H_s is significant wave height ,T_p is peak of the wave period, T_e is the energy period and α depends on the type of dominant wave spectrum in the region (Abbaspour and Rahimi, 2011).

2.2. Wave power in the Persian Gulf

To estimate the wave power in a region, need to measure wave characteristics in a long-time range. Some interrupted and scattered data of wave characteristics are available in Iran Meteorological Organization and National Iranian Oil Company

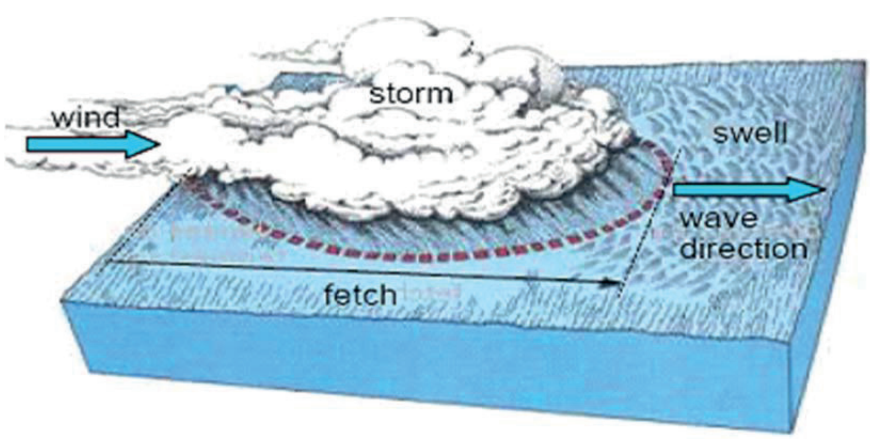

Figure 1. Waves generation process by wind and storm in the Fetch

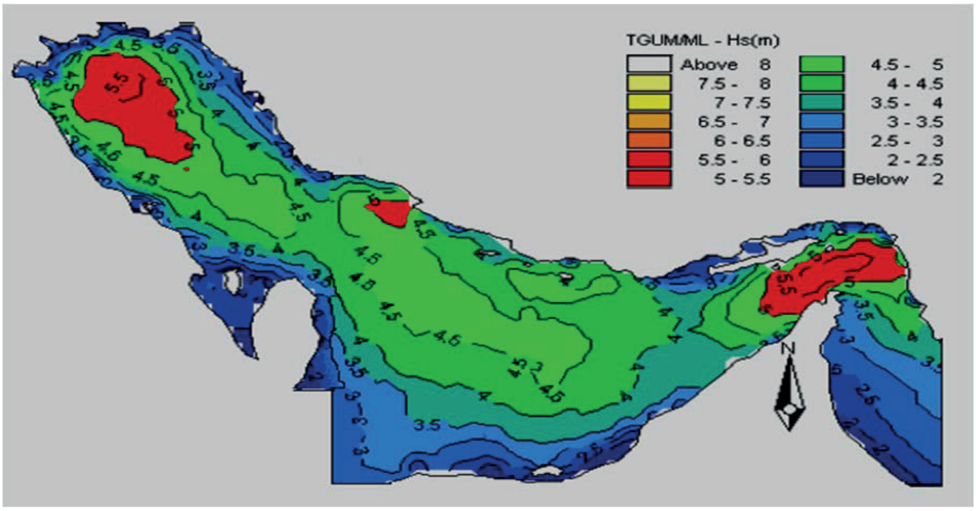

Figure 2. Estimating maximum wave height in Persian Gulf (ISWM, 2008)

buoys from 1995. Furthermore, some data are in Ports and Maritime Organization (PMO) buoys in the Persian Gulf from 2006 (Taebi *et al.*, 2008; Ghaderi and Mazaher, 2010; Abbaspour and Rahimi, 2011; Alamian *et al.*, 2014). Moreover, Iranian Sea Wave Modeling (ISWM) project was performed by the PMO using wind data from 1992 to 2002. According to the ISWM, Pars-Moskowitz spectrum was defined in Persian Gulf (α = 0.86). Figure 2 indicates estimation of the maximum wave height in a hundred-year period (ISWM, 2008).

The average wave power in the ports of Persian Gulf or Iran's islands, are approximately estimated based on the waves' characteristics measurement or waves modeling. Table1 shows all estimations, and the values in the table are derived from different research estimations. Thus, to design a converter or to find the location of waves' energy absorption, more information of a specific project is necessary.

2.3. Wave energy absorption technologies

On average, the wave energy is five times of wind energy and 12.5 times of solar energy (Fadaeenejad *et al.*, 2014). Thus, in the past few decades, designing the systems of wave energy absorber has been one of the most challenging issues in the field of renewable energy. These technologies

Table 1. Approximate estimation of waves' power average on the islands of the Hormuz Strait in the Persian Gulf and Iranian ports (Taebi *et al.*, 2008; ISWM, 2008; Ghaderi and Mazaher, 2010; Abbaspour and Rahimi, 2011; Alamian *et al.*, 2014)

Islands	Wave power average *	Port name	Wave power average *
Hormuz	8-11.7	Booshehr	3.5-5.7
Qeshm	8-10.5	BandarAbbas	2.3-5.5
Hengam	8-10.7	BandarLengeh	3.8-5.6
Larak	9-12	Jask	4-6.5
Siri	7.5-9	MahShahr	2.3-3.8
AbuMoosa	7-9	Ramsar	2.8-5.2
Kish	8-10	Anzali	3.6-5.5

* In 2002 and unit of kW/m ** Southeastern part

Table 2. Wave energy converters in European and American Islands (Drew *et al.*, 2009; Antonio and Falcao, 2010; Fadaeenejad *et al.*, 2014)

Converter name	Location	Output Power (kW)	Average wave power (kW/m)
Pelamis	Scotland: Orkney Island Italy: Sardinia Island	750	40
Wave Dragon	Denmark & Portugal & Greek Island	250	24-60
AquaBuoy	USA: Oregon & Portugal: Maderira Island	250	15-50
Wavebob	Ireland: Aran Islands	500	20-70
OPT	USA: Hawaii Islands	50	40
Oyster	Scotland: Orkney Island	300	20-40

are constantly optimizing to reduce the costs of investment, maintenance and energy production. Table 2 shows some models of wave energy converters in the islands in Europe and America.

Wave energy converters are usually classified based on the installation position and harvesting methods (Fadaeenejad *et al*, 2014). The installation position of wave energy converters is divided into three groups: offshore, near-shore and shoreline, and based on the wave profile, geography and topography of the area, and power consumption (Pecher, 2012). Wave energy harvesting method or device performance usually includes five groups, wave aggregation and soar waves on a sloping surface, oscillating water column, roll-surge fluctuation, Heave buoy oscillation, and wave energy attenuation (Fadaeenejad *et al.*, 2014). Figure 3 indicates a type of classification of wave energy converters (Drew *et al.*, 2009; Pecher, 2012). The converter type and its operation are determined based on the wave predominant profile in an area (frequency and amplitude), installation position, consumer of electricity (residential, commercial, industrial), and the amount of electricity needed (Wacher and Neilsen, 2010; Pecher, 2012).

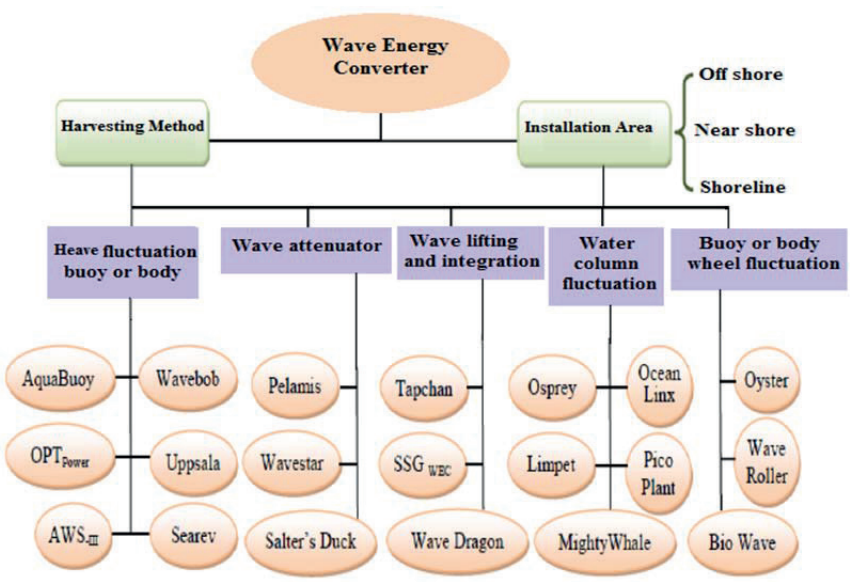

Figure 3. Different wave energy converters according to harvesting methods

Figure 4. Prototype of point absorber wave energy converters

2.4. Point Absorber wave energy converter

In recent decay when the construction of wave energy convertors is industrialized and commercialized, different methods have represented for attracting the energy of wave amplitude variations. Wave energy harvesting by Heave buoy fluctuation was really successful absorber and some systems such as OPT, Aquabuoy, Uppsala, Wavebob, Searev, and L10 Buoy, have bring into the commercialized field. Figure 4 shows some point absorber converters that absorb wave energy (changes in sea level) by Heave buoy method (Pecher, 2012).

2.4.1 Wave energy absorber system in the Heave fluctuation converters (point absorber)

Point absorber converters, by a floated system (buoy) absorb the energy of sea level changes (wave), and almost all industrial and semi-industrial converters use one buoy to absorb the energy. In each wave passage, the buoy stats to the Heave vibration (in vertical direction) in a same phase or a bit phase difference with transmitting wave. The wave Power Take-Off (F_{PTO}) in Equation (3) resulted from the displacement difference (ΔZ) and the Heave speed difference (ΔU) between a buoy (F) and a submerged converter (R).

$$F_{PTO} = C_{PTO} \times \Delta U_{F,R} + K_{PTO} \times \Delta Z_{F,R} \qquad (3)$$
$$\Delta U_{F,R} = U_F - U_R \quad , \quad \Delta Z_{F,R} = Z_F - Z_R$$

which C_{PTO} is damping coefficient of the power take-off, K_{PTO} is roughness coefficient, U is Heave speed, and Z represents the vertical displacement (Yu and Li, 2014). Figure 5 shows the Aquabuoy converter and energy absorption method due to the fluctuation of Heave buoy during upward and downward movements.

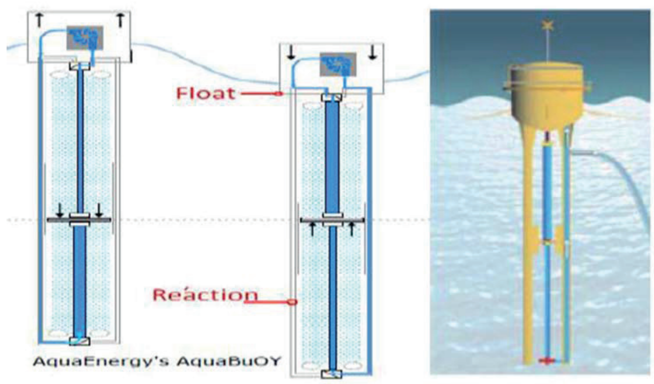

Figure 5. Aquabuoy submerged converter and its energy absorption method

2.4.2 Energy storage and conversion system in Heave fluctuating converters (point absorber)

Point absorber converters convert the energy absorbed by buoy to electrical energy in two methods: using a linear generator, and utilizing a circuit under hydraulic pressure. The first method, linear generator system (electromagnetic system), a buoy connected to an electromagnetic system with a rod, and over every wave, the Heave fluctuation is caused the magnet vertical displacement in the

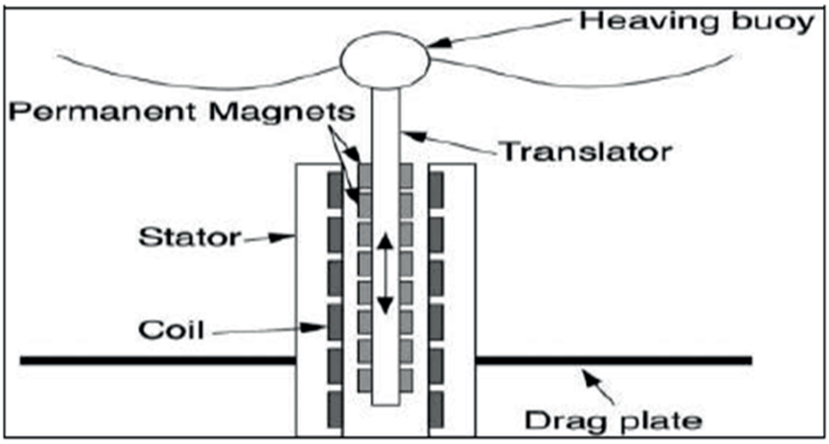

Figure 6. Electromagnetic system in the point absorber converter (Drew *et al.*, 2009)

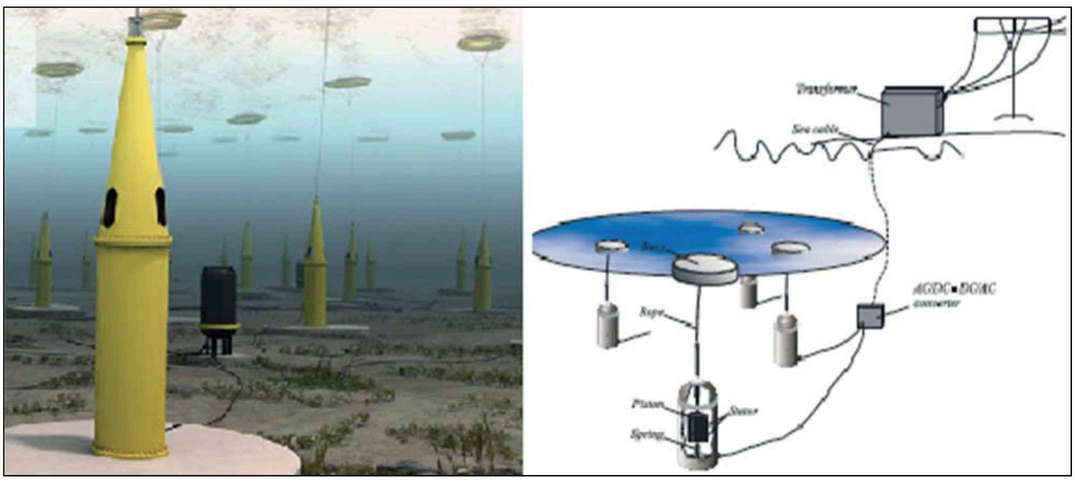

Figure 7. Direct conversion of energy by a linear generator in Uppsala converter (Pecher, 2012)

magnetic field and produces the electricity. This system is applicable in Uppsala converter, L10, and some OPTs. In this method, the storage of harvested energy is not possible. Figure 6 shows the details of linear generator in L10 converter, and Figure 7 represents the energy conversion method with a linear generator in Uppsala converter.

The second method, using hydraulic circuit system, the intake power is converted to the fluid pressure (hydraulic pressure). Moreover, this method is able to store the extracted energy in the form of fluid pressure accumulation (Hydraulic). Energy absorbed by the buoy is transferred to a rod connected to the hydraulic piston (Actuator), and then is converted into hydraulic pressure. An accumulator stores this transmitted pressure and the system uses this pressure to launch the hydro-generator. The method detail is available in Figure 8 and the converters such as Wavebob, Aquabuoy, and OPT Hydraulic use this method (Drew *et al.*, 2009). The seawater in the internal circuit system of the Aquabuoy converter is under pressure of the absorbed wave power. However, the rest of the converters use the hydraulic oil. Moreover, these converters' circuits are under the hydraulic pressure in both directions (+, -) of Heave buoy.

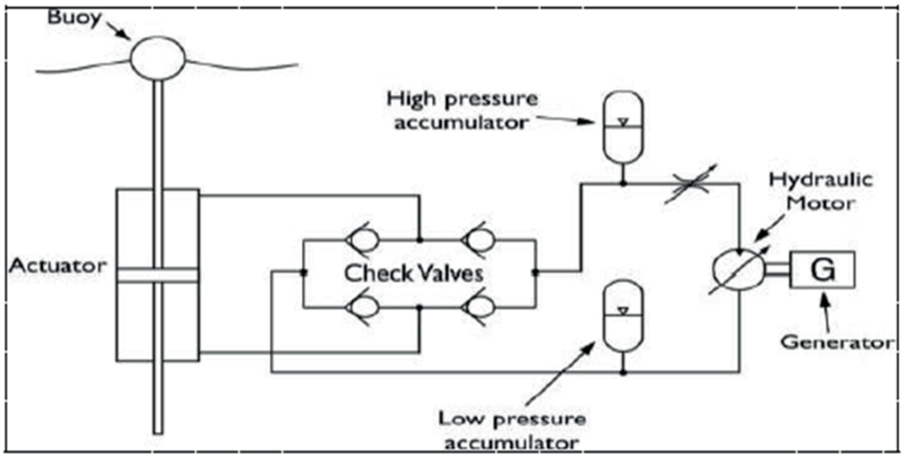

Figure 8. Performance algorithm, storage method, and energy conversion in a circuit system under hydraulic in the Wavebob and OPT converters (Drew *et al.*, 2009)

2.4.3 Restraint system in the point absorber converters

There are four methods in inhibiting the conventional point absorber converters. As is evident in Equation (3), the absorbed energy (F_{PTO}) is due to displacement difference ($\Delta Z_{F,R}$) and vertical velocity ($\Delta U_{F,R}$) of the buoy and the submerged converter. Moreover, increasing this difference caused rising absorbed energy (harvesting energy). In fact, the efficiency and output power of the converter has a direct relationship with the difference between $\Delta Z_{F,R}$ and $\Delta U_{F,R}$.

2.5. Suggested ways to extract short-height wave energy

As proposed, conventional point absorber converters for ocean coastlines have been designed and built with average power between 30 to 40 kW/m. Average wave power appraised between 3 to 6 kW/m in the Persian Gulf coastlines and between 7 to 12 kW/m in the islands of Hormuz Strait. Therefore, some changes in these converters are necessary to harvest short wave (less than one meter) energy from the Persian Gulf by Heave buoy fluctuation method.

According to Equation (3), increasing displacement and Heave buoy velocity and reducing these parameters in the submerged body can increase the output power and the efficiency. Therefore, the following ways are suggested to increase the efficiency of point absorber converters and short wave energy extraction in the Persian Gulf.

- Change the shape of buoy; the buoy shape in the immersion part is consistent with the wave transmission and the rotational motion of wave orbital which increase the fluctuation of Heave buoy (Pastor and Liu, 2014)
- Select the appropriate diameter for buoy; the proportionally between the diameter and wavelength, reduction the roll and increase of the Heave buoy frequency (Pastor and Liu, 2014).
- Use the resonance effect in buoy; the consistent of natural frequency of buoy and the predominant frequency in the region cause the resonance effect and increase of vertical displacement of Heave buoy (Koh *et al.*, 2014).
- Use the depreciation reducing methods in transmission of F_{PTO} to internal conversion system.
- Using hydraulic pressure circuit system to store and convert the energy (Figure 7).
- Using Heave plate to control converter body motion in Heave and Roll direction

(Yu and Li, 2014).

❖ Using tension leg anchor instead of Kuttner containment anchor; this anchor inhibits the Heave motion on the body and can control the Heave in the submerged body and increase the resulting pressure in the internal hydraulic circuit in the converter.

2.6. Converter design based on the waves' characteristics in the Persian Gulf

To apply the suggested seven designing ways in the previous section, more information about the wave profile, cumulative percentages of wave frequency, and wave amplitude should be available. Thus, the Persian Gulf region, Asaluyeh port, and Faror Island (near Kish Island) were investigated based on the data obtained from the PMO database. Figure 9 indicates the cumulative percentage of wave frequency in Asaluyeh port and Faror Island during one year. The investigation resulted that more than 60% of waves have frequencies between 1 to 1.8 rad/s and more than 83% of the waves' height are less than 100 cm. The short height of

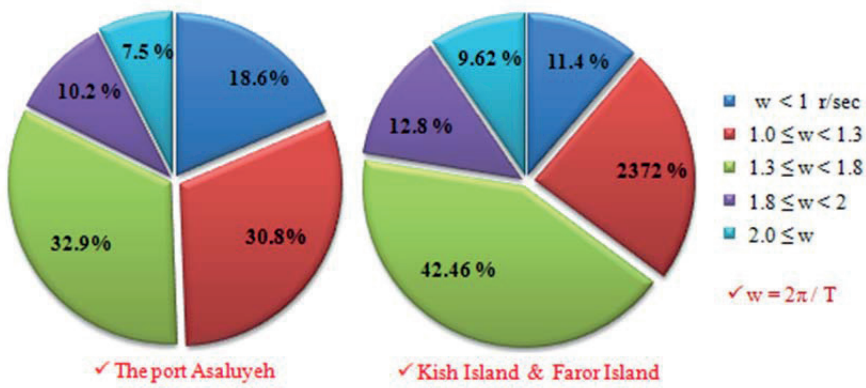

Figure 9. Cumulative percentage of waves' frequency in the Asaluyeh port and Faror Island in the Persian Gulf (2003)

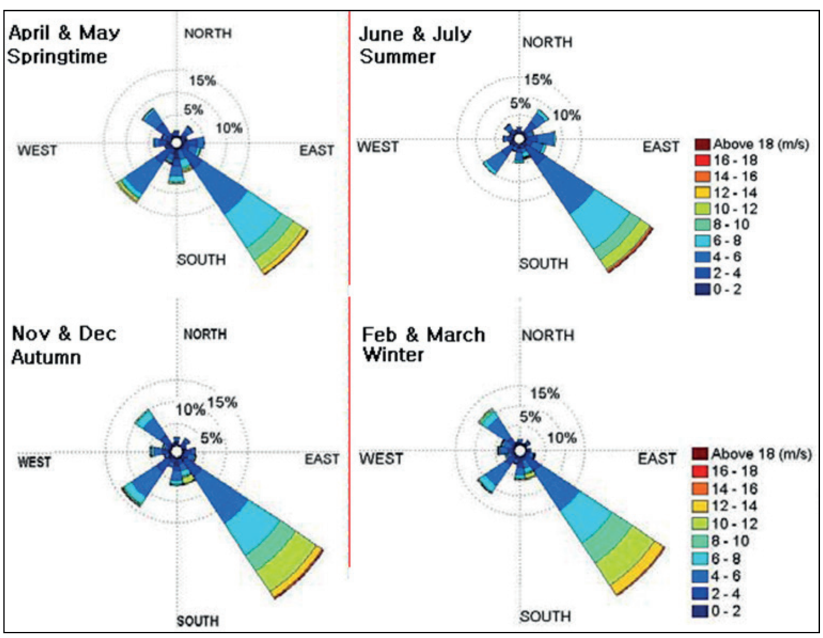

Figure 10. Seasonal Windrose during 2003 to 2007 in Arzaneh Island station in the United Arabic Emirates in the south of Persian Gulf (Golshani, 2010)

the waves in Persian Gulf is due to small fetch in the sea, geography conditions, and topography of the region. Actually, longitude and latitude of the Persian Gulf and a little climate difference with its surrounding plateau especially in south of the Persian Gulf, make the variations of wind speed and wind direction restricted and stable in most of the times during the year (Golshani, 2010).
The small changes of wind speed and wind direction in the Persian Gulf, generates the uniform short waves with little frequency changes. Figure 10 shows the Wind-rose graph of the hourly winds in different seasons. The hourly wind data for two months of each season during five years (2003-2007) obtained from a station in the Arzaneh Island coast (in the United Arabic Emirates in the south of Persian Gulf). The figure clearly indicates the steadiness of wind direction and low variations of wind speed in the Persian Gulf (Golshani, 2010).

2.6.1 Designing an absorbent buoy

According to the statistics presented in Figure 9 designing a buoy with natural frequencies between 1 to 1.8 rad/s increases the possibility of resonance in the buoy, therefore, the natural frequency range for the buoy must be in the same frequency range of waves.

Koh and his colleagues stated that resonance in the energy-absorbing buoy could enhance the output power up to three times (Koh *et al.*, 2014). Figure 11 shows the results of the research on cylindrical buoys with different natural frequencies.
A study at the University of Louisiana represented that in the extraction of wave energy, the consistent of buoys diameter with wavelength increases the Heave motion and reduces the negative effects of the Roll, and a conical buoy is more useful than a spherical buoy shape in the wave energy harvesting (Pastor and Liu, 2014).
Based on these researches and to increase the Heave motion in buoy, to consist the buoy's diameter with wavelength, to reduce the buoy roll motion, to absorb maximum wave power, and considering the existing data in Asaluyeh port and Faror Island in Persian Gulf, two control factors in Equation (4) were applied on the characteristics of the waves and different diameters of the buoy. In fact, initial diameter of the buoy specified between 2.4 to 3.8 meters.

$$\frac{H}{D} \prec 1.5 \quad , \quad D \prec \lambda/5 \tag{4}$$

which D is buoy diameter, H is wave height, and λ is wavelength.
The buoy shape in the immersion part is consistent with the wave transmission and the rotational motion

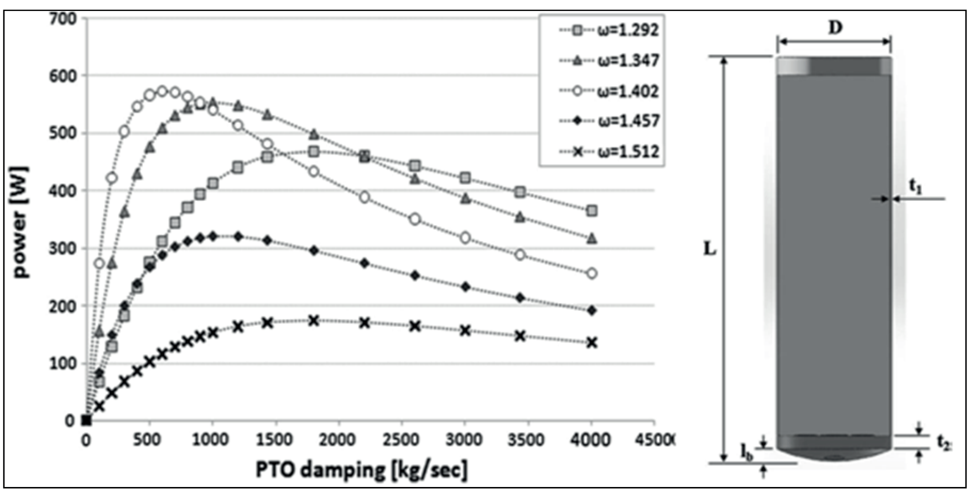

Figure 11. A research buoy and the resonance effects on the harvested energy in a point absorber converter (Koh *et al.*, 2014)

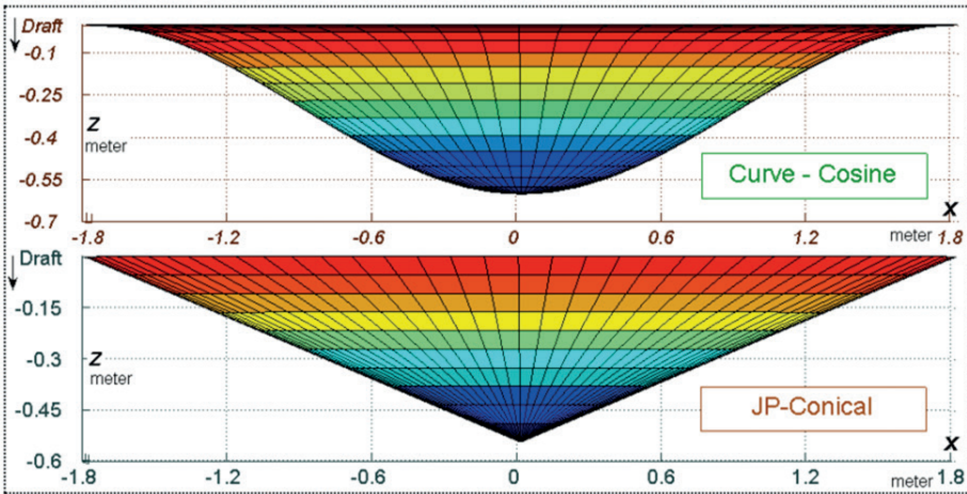

Figure 12. JP-Conical buoy (down) and Cosine curve buoy (up)

of wave ring can increase the Heave fluctuation of the buoy. Thus, the buoy found a cylinder shape, but in the immersion part, it is in a Cosine shape. This means that the Cosine shape of the buoy is for consistency in encountering with the sinusoidal wave. To control the hydro-dynamical response of this buoy in comparison with the Pastor study's results on a conical buoy (Pastor and Liu, 2014), the buoy diameter specified 3.6 meters, for having equal effect in both buoys. Figure 12 indicates spherical buoy in Pastor's research and the Cosine curve buoy.

To validate the results the wave impact level should be the same in both buoys. Table 3 shows the dimensions of different buoys; JP-Conical, Cosine Curve, and Conical-2. The Conical-2 buoy is completely similar to JP-Conical buoy and it is just represented for validation of hydro-dynamical analysis. In the table, D is buoy diameter in meter, Draft is the immersion depth in meter, Area is the wave affection region, and the Slope is the gradient of wave pressure with immersion depth of buoy.

According to Pastor's research and the results in the Figure 13, wave energy extraction is slightly relatively different in Cosine buoy, conical buoy and Hemisphere buoy.

2.6.2 Converter design based on the wave characteristics in the Persian Gulf

To design the short wave energy converter and to apply the seven proposed ways, more information should be available such as waves' profile and the cumulative percentage of wave frequency and wave amplitude. Therefore, the case studies were conducted on the Persian Gulf, the Asaluyeh port, and the Faror Island based on the data obtained from PMO. Figure 9 indicates the cumulative percentage of waves' frequency of the Asaluyeh and Faror Island during one year. As shown in the figure, more than 60% of waves' frequencies are between 1 to 1.8 rad/s and more than 83% of the waves' height is less than 100 cm. Thus, the internal system in the converter must be a hydraulic pressure circuit to be

Table 3. Pastor buoy dimensions and two other buoys for comparing the amount of harvested wave energy

Buoy	D (m)	Draft (m)	Area (m^2)	Slope
JP-Conical	3.6	0.54	44.378	18%
Conical	3.6	0.54	44.378	18%
Cosine Curve	3.6	0.60	44.369	20%

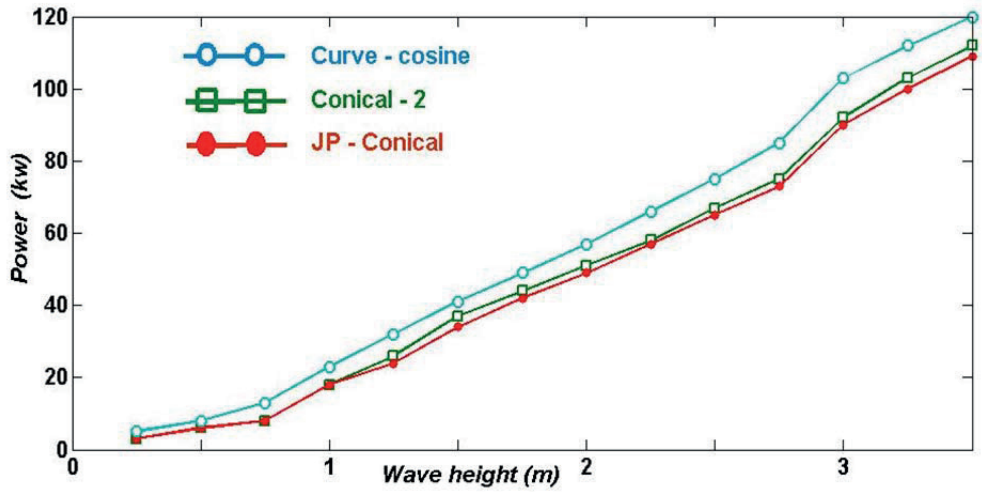

Figure 13. Comparison between absorbed energy by JP-Conical and Cosine Curve buoys

able to absorb, store, and convert the wave energy in the Persian Gulf.

Electromagnetic system or linear generator that is applicable in the point absorber converter, Upsala and L10 buoy, can be use and operate in the shores with 40-kW/m wave power and the wave height of more than one meter (Drew *et al.*, 2009). Therefore, the OPT Hydrolic converter was selected with a hydraulic pressure circuit with commercial models of PB10, PB35, PB150, and PB350. For validating the results, the Yu and Li model converter was applied. Figure 14 shows the point absorber converter to perform the tests and hydrodynamical analysis in the tank, which the buoy dimensions and Heave plate are almost equal to the factors in OPT-PB150 converter, correspondingly (Yu and Li, 2014).

2.6.3 Design of Containment Systems

The containment system used in this research is a tension leg anchor. Using this anchor with initial stretch of more than bulk force of the absorber buoy is very effective in generating the hydraulic pressure in the system internal circuit. Most of the point absorber converters use a Kuttner anchor to

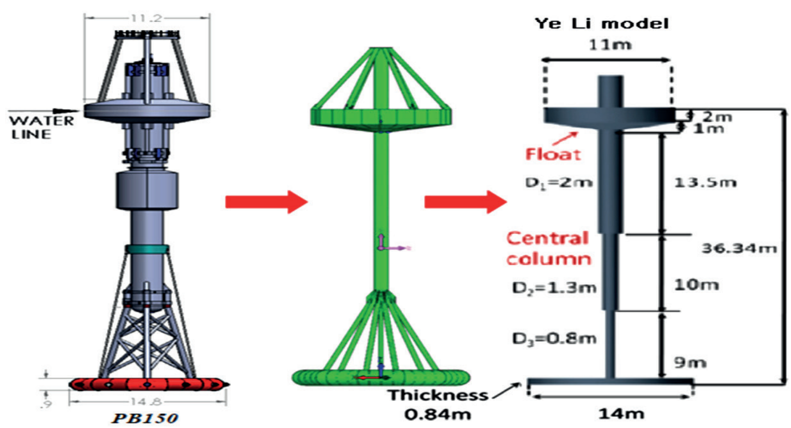

Figure 14. Schematic of OPT-PB150 point absorber converter and the Yu and Li model in laboratory test and hydrodynamical analysis (Yu and Li, 2014)

maintain the position of the device.

In this study, a model was designed according to the Yu and Li model. The hydrodynamical analysis was performed in Moses software, for the designed model in two methods, one without anchor and the other with a tension leg anchor. Figure 15 shows a schematic of two models and Figure 16 indicates the comparison of this study results with the analysis of Yu and Li model to apply a regular wave with a height of 2.5 meters and a period of 10 seconds. Therefore, variations of Heave fluctuation can be controlled by tension leg anchor and actually the Heave fluctuation is negligible and almost zero. Figure 17 is the Yu and Li study results.

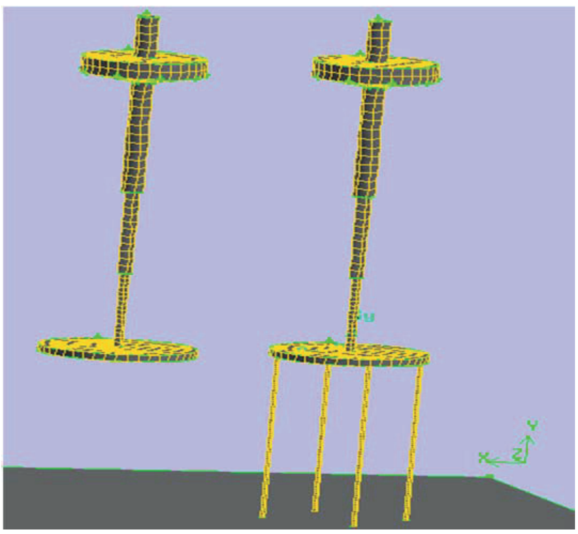

Figure 15. A point absorber wave energy converter, with a tension leg anchor, and without an anchor in accordance with the Yu and Li model (OPT-PB150)

According to the Equation (3), by reducing Heave displacement in the body (Z_R), the extracted wave power (F_{PTO}) rises. The rigid tension leg anchor inhibits the Heave motion of converters' body and the values of U_R and Z_R are negligible. Hence, in the case of using tension leg anchor the Equation (3) is simplified to Equation (5).

$$F_{PTO} = C_{PTO} \times U_F + K_{PTO} \times Z_F \quad , \quad U_R \cong Z_R \cong 0 \qquad (5)$$

2.6.4 Design of Storage and energy conversion system based on tension leg anchor

In this research, by applying some changes in the algorithm of the point absorber wave energy converter (Figure 7) and utilizing of an inhibitory tension leg anchor instead of a Kuttner anchor or a three-point anchor, a new method was represented to extract short-wave energy (less than one meter) by the Buoyancy force and buoy weight, for the Persian Gulf. The tension leg anchor makes a fixed position for the cylinders of converter internal circuit (Figure 18) and a negative reaction against the buoy transitional force. In this method, the buoy weight generates the pressure in the converter internal circuit, and the wave height is effective only on the Heave displacement and the density in the converter internal circuit. Figure 18 shows that positive Heave motion in a buoy (+z) when passing wave's crest, the hydraulic oil is driven from

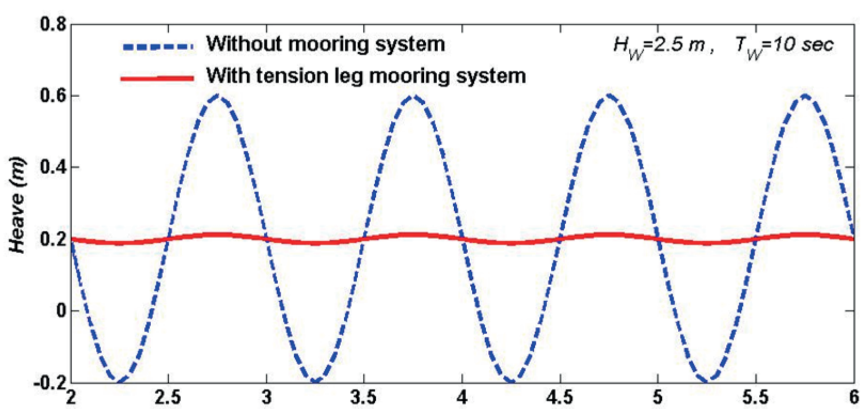

Figure 16. Heave oscillations in the submerged body of point absorber converter

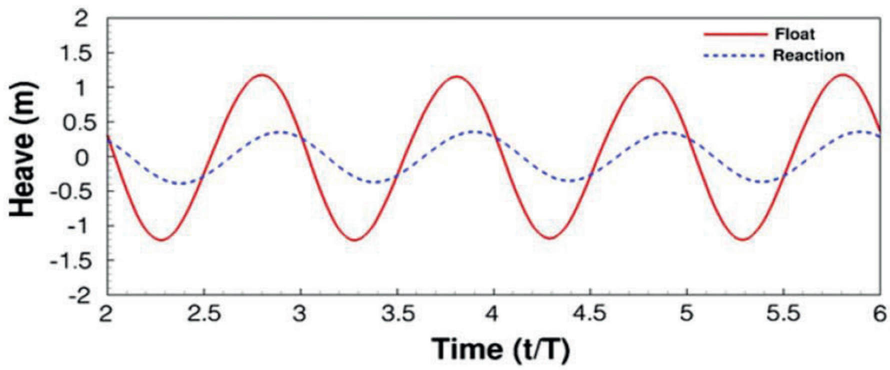

Figure 17. Heave oscillations in the submerged body of the Yu and Li model (H_W = 2.5 m, T = 10^S) [Yu and Li, 2014]

reservoir into the hydraulic cylinder (Actuator). Moreover, the negative Heave motion in the buoy (-z) when passing wave trough, the hydraulic oil under pressure is driven toward the accumulator for storing. Of course, the buoy downward motion is possible when the resulting pressure is more than the pressure in the accumulator. Otherwise, the wave can only cause the Heave positive displacement in buoy and does not create additional pressure on the system. In this way, the resulting pressure in the internal circuit system of the converter, obtains from Equation (6) that F_W and F_B, F_{WB}, are wave power (kN), the buoy's Buoyancy force, and weight force of the buoy, respectively. All the forces change relative to time, and A is the cross section of the cylinder (m^2) and is determined by density and pressure required in the converter's internal circuit.

$$P_{PTO}(t) = (F_{WB}\ (t) + F_B(t) + F_W(t)\ /\ A\ \ (KPa) \qquad (6)$$

3. Modeling to calculate the extracted power

Figure 19 illustrates the point absorber converter in order to hydrodynamical analysis in Yu and Li model (Yu and Li, 2014). Applying a wave on the converter, the spring length and the resulting

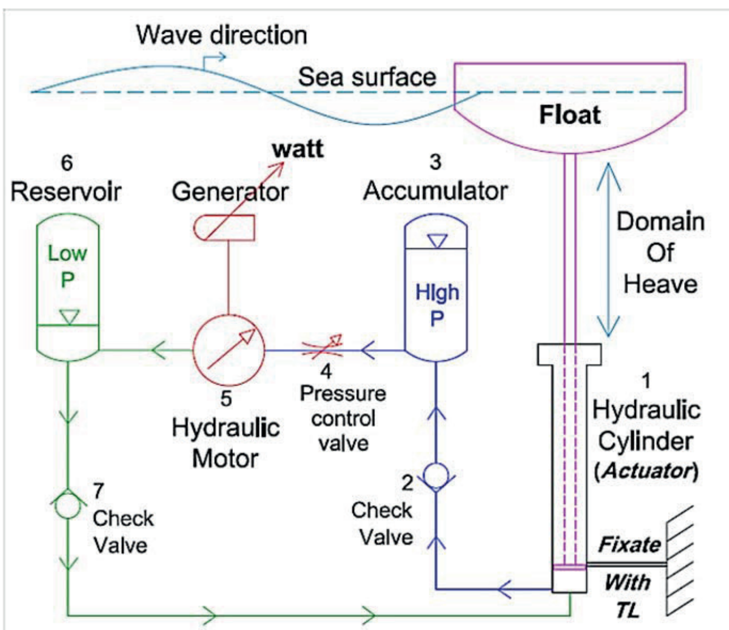

Figure 18. Operation algorithm of a system under the hydraulic pressure for converting short-height wave energy (less than one meter) in Persian Gulf

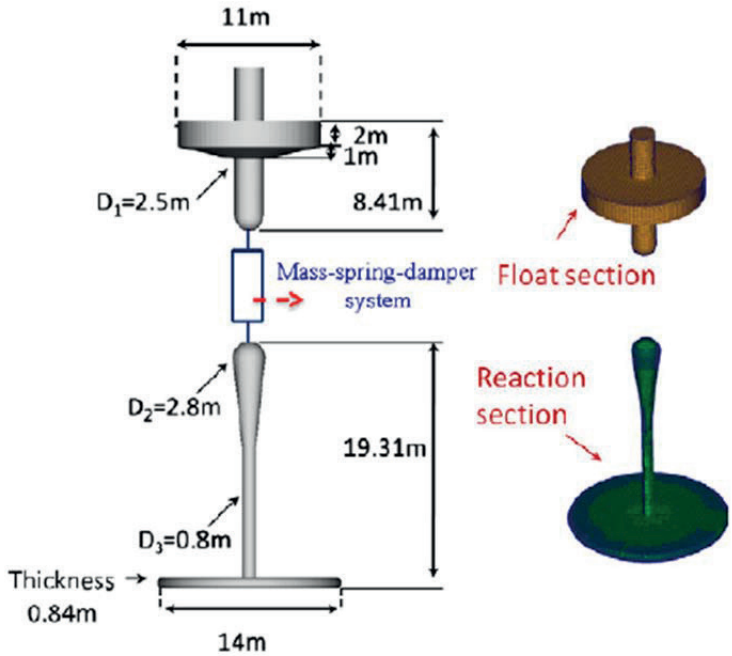

Figure 19. The point absorber converter in Yu and Li model (Yu and Li, 2014)

damping in dampers can express the extracted power from the wave. In addition, the Equation (3) summarized to Equation (7). The relationship represents that the extracted power is based on the squared difference of Heave displacement rate in the buoy (U_F) and Heave plate in converter (U_R). In fact, different values for the damper (the effects of internal system) can calculate the extracted wave energy (P_{PTO}).

$$P_{PTO} = C_{PTO} \times (U_F - U_R)^2 \quad (7)$$

By identifying the damping coefficient (C_{PTO}), the internal circuit of hydraulic system was designed based on the algorithm given in Figures 7 and 18. The results due to the variations of C_{PTO} affect on the extracted power (P_{PTO}) and are shown in Figure 20.

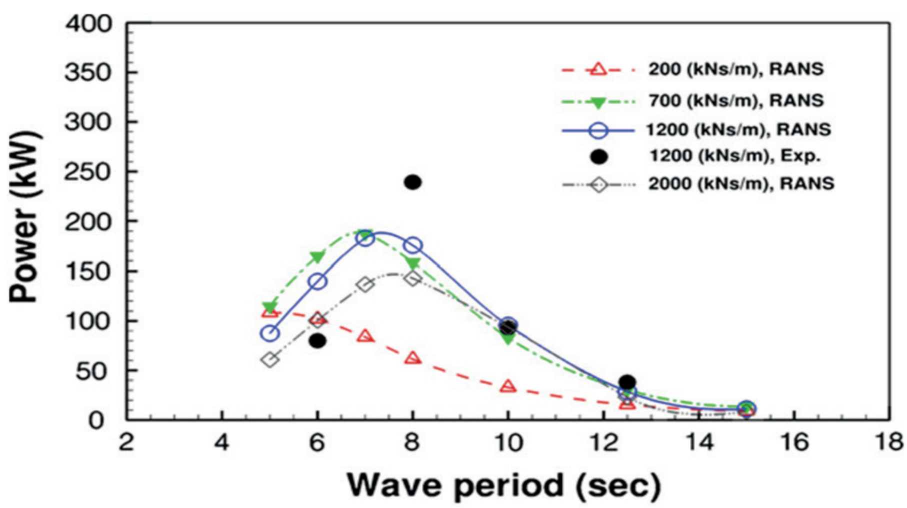

Figure 20. Obtained power by the buoy in Yu and Li model from a wave height of 2.5 m (Yu and Li, 2014)

4. Converter design based on the waves in Persian Gulf

According to research by Pastor and Liu (2014) and the analysis conducted on three different wave energy absorber buoys (Figure 13), a Cosine curve buoy with the natural frequency (W_n) of 1.56 rad/s was selected. Actually, based on the available data (Figure 9), the occurrence of this frequency in Asaluyeh port and Faror Island in the Persian Gulf is more possible.

In accordance with the results in Figure 16 and its related analysis, it stated that reducing the Heave motion could cause increasing output power and the system efficiency (Equation 3). Furthermore, the algorithm in Figure 18 could be applicable for energy absorption, storing and short wave energy conversion in the Persian Gulf. Therefore, a converter was designed to absorb wave energy from the waves with less than one meter height. This plan can be used to absorb wave energy on accordance with the wave profile in the Persian Gulf. The dimensions of the designed converter are available in Table 4.

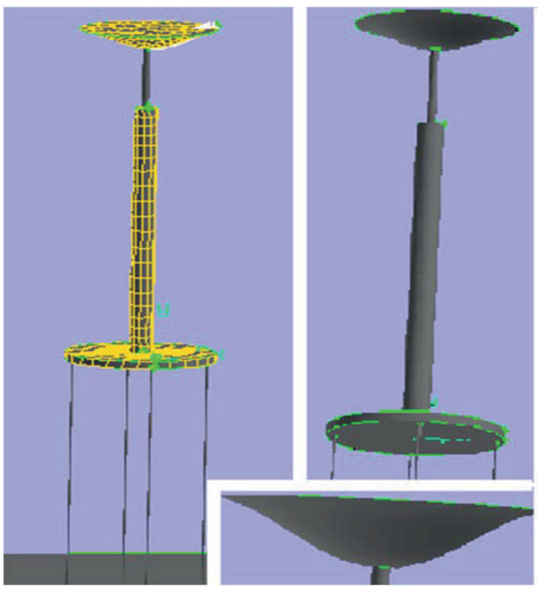

Figure 21. A point absorber wave energy converter in the Persian Gulf with Cosine-shape buoy and tension leg mooring

Conclusion

Due to the short amplitude of waves in the Persian Gulf, extracting wave energy with current conventional converters is not technically and economically justifiable, because these devices algorithm is applicable for the ocean waves with average power between 30 to 40 kW. Actually, the waves' power in the Persian Gulf on average is ranged between 3 to 21kW/m. The wave energy extraction is slightly different in three types of buoy; Cosine curve buoy, conical buoy, and Hemisphere buoy.

In fact, a resonance effect in energy absorbing buoy in point absorber converters can increase the output power up to three times. Therefore, the designed buoy for short wave energy converter in the Persian Gulf had a natural frequency of 1.56 rad/s. Based on the data available for Assaluyeh port and Faror Island the occurrence of this frequency in the Persian Gulf waves is more probable. Containment of Heave motion of the converter body, and Heave displacement are negligible and almost zero, because of tension leg anchor.

Table 4. Point absorber wave energy converter characteristics (Persian Gulf)

Part	Diameter	Height	Area (m^2)	Slope
Cosine buoy	3.6	0.60	44.369	20%
Body shaft	0.2	2	_	_
Body spare	0.6	8	_	_
Heave plate	4	0.25	_	_

In addition, a new system was designed for storing and converting extracted energy in a point absorber system according to a tension leg anchor. Therefore, two forces come into consideration to absorb wave energy, buoyancy force and weight. Moreover, investigating different technologies and algorithms of the point absorber converters, seven suggestions were recommended to change the systems of wave energy absorption, energy storage, and extracted energy conversion, and its containment. The solutions are effective and efficient for the energy extraction from short waves with less than one-meter amplitude in the Persian Gulf. Hence, analyzing the absorption of wave energy in the point absorber converters, the cylindrical buoy in the Cosine curve form was designed to coincide with the transitional and rotational motions of the water particles in the wave circle. Finally, the results showed the superiority of Cosine curve buoy relative to Hemisphere and Conical buoys.

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