New method for converting sea wave energy

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Abstract

High force of sea waves is a huge renewable energy resource and sea waves, will play an important role in tomorrow's electricity production. This paper presents a new method for converting sea wave energy to continuously crank shaft motive force by a new apparatus named Engine for Producing Energy from Sea Waves. There by, this apparatus can be used for producing AC electricity from sea waves, which is also economically important in sea wave energy converting. Besides, this apparatus generates positive moment (crank shaft moment) from sea wave and this makes that, EPEW's RMS moment be more than other devices. Against of other devices EPEW in three dimensions contact with sea waves and absorbs more energy in length of sea shore. In this paper we design, simulate and calculate amount of energy for this new WEC.

1. Introduction

The interest in finding a way to convert energy in ocean waves into electricity has been increased during the last years, but the development of an offshore wave energy technology is still very scattered [1].

In practice, three methods of energy storage have been adopted in wave energy conversion. An effective way is storage as potential energy in a water reservoir, which is achieved in some overtopping devices, like the Wave Dragon (Soerensen et al., 2005) and the Tapchan (Mehlum, 1986). In the oscillating water column type of device, the size and rotational speed of the air turbine rotor make it possible to store a substantial amount of energy as kinetic energy (flywheel effect) (Falcão and Justino, 1999); this is particularly true for the Wells turbine, whose rotor diameter and blade tip speed are both substantially larger compared with the self-rectifying impulse turbine (that has been proposed as an alternative to the Wells turbine).

In a large class of devices, the oscillating (rectilinear or angular) motion of a floating body (or the relative motion between two moving bodies) is converted into the flow of a liquid (water or oil) at high pressure (HP) by means of a system of hydraulic rams (or equivalent devices). At the other end of the hydraulic circuit there is a hydraulic motor (or a high-head water turbine) that drives an electric generator. The highly fluctuating hydraulic power produced by the reciprocating piston (or pistons) may be smoothed by the use of a gas accumulator system, which allows a more regular production of electrical energy. Naturally the smoothing effect increases with the accumulator volume and working pressure. This kind of power take-off system is employed e.g. in the Pelamis wave energy converter (Pitzer et al., 2005) [3].

Briefly, The sea wave energy can be absorbed by wave energy convertors (WEC) in a variety of manners, but in most of the existing methods, WEC is consist of a buoy That is float on the sea level and fluctuates with waves. This WEC systems have some problems, First one is that ,the buoy, must be enough light not to drown in sea and be able to fluctuate by waves, second is that this WEC can' t absorbed all energy of sea waves (because of first problem). Another problem in sea wave converting to electricity is, generator input is irregular and therefore voltage and current amplitude and frequency is irregular [1].

This paper defines a new method for converting sea waves to continuously crank shaft moment. In this new method sea wave are absorbed by a new WEC and are converted to the mechanical energy, this WEC absorbs wave energy by moving parallel to sea level and it's not float on sea waves, and this makes possible for this WEC to absorbs more energy of sea waves. After this stages mechanical energy which has converted by WEC smoothes by a crank shaft. This smooth torque of crank shaft can be used for generating AC electricity (not considered here).

2. The EPEW convertor

The EPEW is formed from a new mechanical WEC that it fixed on the sea level against sea wave, without floating on the sea. The base idea in designing EPEW's WEC system is on placing some plates in front of sea wave pressure. According to the equation (1) if we have a plate in front of a constant pressure, we can absorb force by this way. Supposing that the sea wave pressure is constant, by placing a plate in front of sea wave and allow it to move with waves we can absorb sea wave energy, while we can bring this plate to it's first place and make a loop motion.

$$F = P \times A \quad (1)$$

EPEW's WEC system is like that the plate survey is variable, in absorbing energy from waves it has maximum survey (to absorb more energy) and in coming back to it's first place it has minimum survey (to loss less energy). In Fig1 and Fig2 you see simplified schematic of EPEW's WEC while a loop motion.

According to our calculation's and design, the minimum amount of absorber plates that a EPEW needs for convert continues energy from sea waves is four plate, this is only minimum amount, and we can increase plates for converting more energy from waves with attention to the sea shore condition.

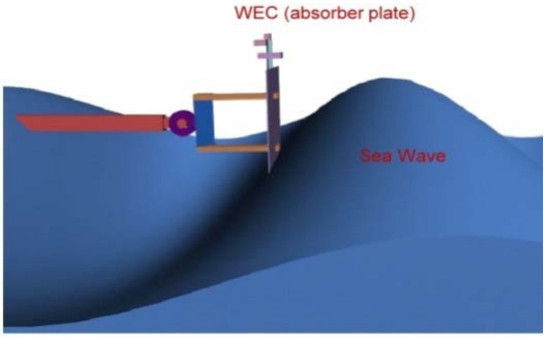

Fig. 1. EPEW's WEC while absorbing energy from sea waves

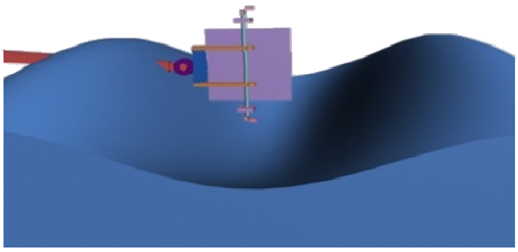

Fig. 2. EPEW's WEC while coming back to its first place

The absorber plates motion and their survey was modeled mathematical. Equations of first plate survey in one period by mathematical modeling are as follow;

For: $0 \leq t < 0.45T$

$$A_1 = x_0 \times y_0 \tag{2}$$

For: $0.45T \leq t < 0.5T$

$$A_1 = \frac{x_0}{0.05T}\left(y_0 \times \sqrt{(0.05T)^2 - (0.45T - t)^2} + h_0 \times \sqrt{(0.05T)^2 - (0.5T - t)^2} \right) \tag{3}$$

For: $0.5T \leq t < 0.95T$

$$A_1 = x_0 \times h_0 \tag{4}$$

For: $0.95T \leq t \leq T$

$$A_1 = \frac{x_0}{0.05T}\left(y_0 \times \sqrt{(0.05T)^2 - (T - t)^2} + h_0 \times \sqrt{(0.05T)^2 - (0.9T - t)^2} \tag{5}\right.$$

$$h_0 \ll y_0 \tag{6}$$

At above equations T is Period of waves (sec), t is Time (sec), h_0 is Thickness of absorber plate (m), x_0 is Height of absorber plate (m), and y_0 is Length of absorber plate (m).

According to the (1) and (2),(3),(4) and (5) amount of absorbed force from waves for one period by first absorber plate is equal to;

For: $0 \leq t < 0.45T$

$$F_1 = P_0 \times x_0 \times y_0 \tag{7}$$

For: $0.45T \leq t < 0.5T$

$$F_1 = \frac{P_0 \times x_0}{0.05T}\left(y_0 \times \sqrt{(0.05T)^2 - (0.45T - t)^2} + h_{0\times} \sqrt{(0.05T)^2 - (0.5T - t)^2} \right) \tag{8}$$

For: $0.5T \leq t < 0.95T$

$$F_1 = -P_0 \times x_0 \times h_0 \tag{9}$$

For: $0.95T \leq t \leq T$

$$F_1 = -\frac{P_0 \times x_0}{0.05T}\left(y_0 \times \sqrt{(0.05T)^2 - (T - t)^2} + h_0 \times \sqrt{(0.05T)^2 - (0.95T - t)^2} \tag{10}\right.$$

At above equations F is absorbed Force by WECs (N), P_0 is Pressure of sea waves (N/m).

In Fig3 you see plot of absorbed force from sea waves by first absorber plate. Negative sign of fore in equation (9) and (10) is obtained during the bringing first absorber plate back to its primary position.

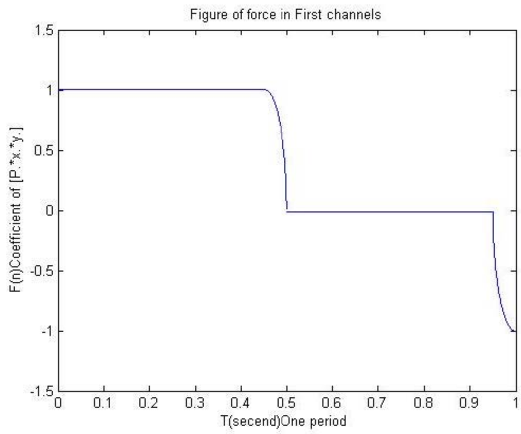

Fig. 3. Figure of absorbed force from sea waves by first absorber plate.

The force equation of other absorber plates is similar to first absorber plates but each of this formula is simulated during specified period. Following figures (Fig4, Fig5 and Fig6) show absorbed force by each plate with respect to the time in one wave period.

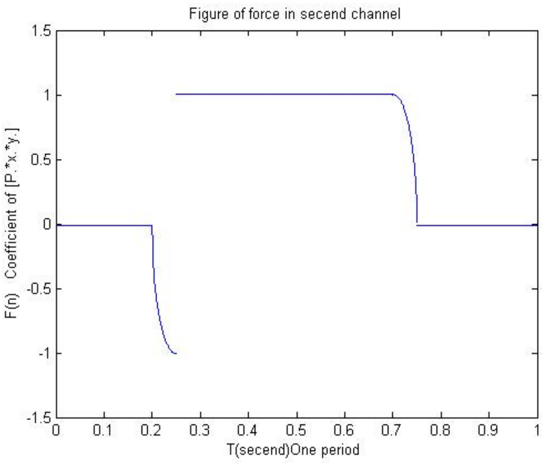

Fig. 4. Figure of absorbed force from sea waves by second absorber plate.

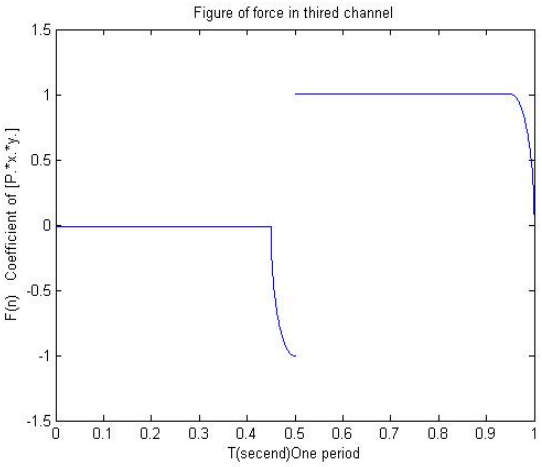

Fig. 5. Figure of absorbed force from sea waves by third absorber plate.

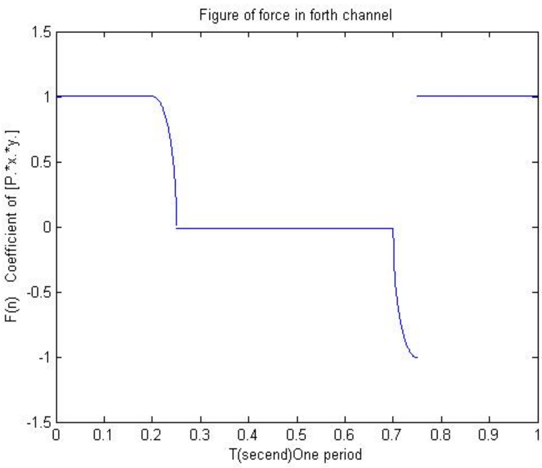

Fig. 6. Figure of absorbed force from sea waves by forth absorber plate.

As has been shown in the above figures, absorbed force some times is equal to zero and sometimes it is negative, for giving positive and constant force we use four of this absorbers plates in different phases of waves, so that we give force from wave in different phases. For giving a continues positive force from sea waves the absorber plates are connected to a crank shaft and their force finally is summed, And total amount of force that absorbed by a four channel (four Absorber plates) EPEW is as follow and its plot is shown in Fig7;

$$F_{total}=F_1+F_2+F_3+F_4 \tag{11}$$

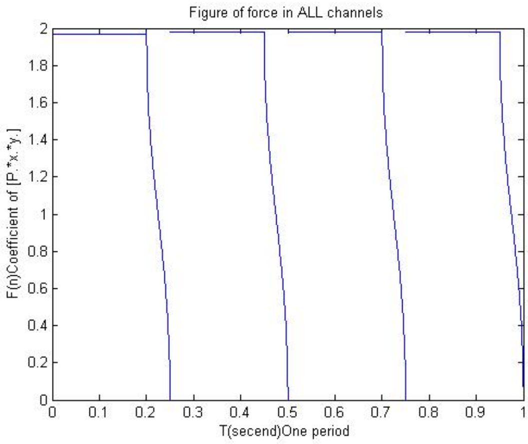

Fig.7. Figure of absorbed force from sea waves by all absorber plates in one period of sea wave.

Amount of force that is transferred by connecting rod to crank shaft is calculate from below formula;

$$\overrightarrow{F_{\lambda_i}} = -F_i.\frac{\lambda_i^2-R_0^2.\sin^2(\frac{\pi.V_0}{2R_0}t)}{\lambda_i^2}\vec{\boldsymbol{i}} + F_i.\,\mathrm{R}_0.\sin(\frac{\pi.V_0}{2R_0}t).\frac{\sqrt{\lambda_i^2-R_0^2.\sin^2(\frac{\pi.V_0}{2R_0}t)}}{\lambda_i}\vec{\boldsymbol{j}} \tag{12}$$

At above equation λ_i is length of ith connecting rod F_{λ_i} is Absorbed force in direction of connecting rod to crank shaft (N), i is Number of plate (channel) and R_0 is Radius of crank shaft (m).

And crank shaft arm (where connecting rod is connect on crank shaft) formula is;

$$\overrightarrow{\mathrm{R}_i} = \mathrm{R}_0.\cos(\frac{\pi.V_0}{2R_0}t-\frac{\pi}{2}(i-1))\,\vec{\boldsymbol{i}} + \mathrm{R}_0.\sin(\frac{\pi.V_0}{2R_0}t-\frac{\pi}{2}(i-1))\,\vec{\boldsymbol{j}} \tag{13}$$

Amount of EPEW's output moment is calculated below equations;

$$\tau_{\lambda_i} = \overrightarrow{\mathrm{R}_0} \times \overrightarrow{\mathrm{F}_{\lambda_i}} \tag{14}$$

$$\tau = \tau_{\lambda_1}+\tau_{\lambda_2}+\tau_{\lambda_3}+\tau_{\lambda_4} \tag{15}$$

$$\mathrm{RMS}(\tau)=\sqrt{\frac{1}{T}\int_o^T \tau_{total}^2.\,dt} \tag{16}$$

τ_{λ_i} is moment of ith connecting rod (N.m) and τ is total torque of crank shaft (N.m).

According to the above equations figure 8 shows EPEW output (crankshaft) moment and RMS moment.

Amount of absorbed energy W(j) from sea waves is calculated from below formula and is shown in figure 9;

$$W(t)=\int_0^T \tau \, . d\theta \qquad (17)$$

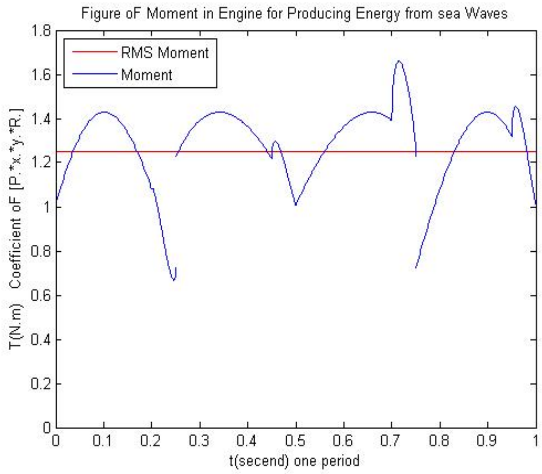

Fig.8. figure of EPEW's output (crank shaft) moment for one period in ideal wave condition.

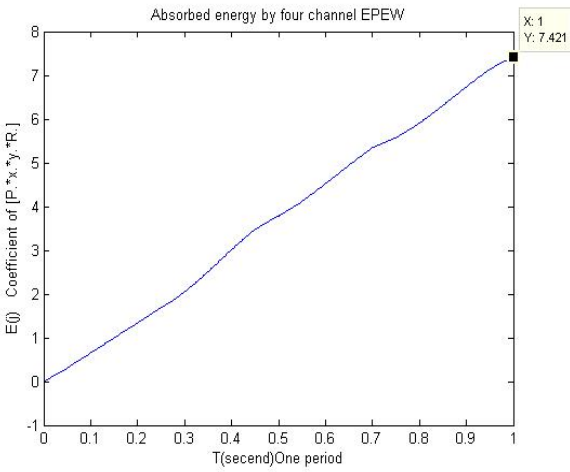

Fig. 9. plot of absorbed energy from sea waves by a four channel EPEW for one period in ideal wave condition. Absorbed energy from sea waves is continues and smooth.

3. Comparison

First advantage of EPEW is absorbing smooth energy from sea waves. Absorbed energy from waves by EPEW is shown in fig9, and absorbed energy by Archimedes Wave Swing is shown in fig10 [4]. EPEW's absorbed energy is more liner in comparison with Archimedes Wave Swing.

Another advantage of the EPEW is converting sea wave to positive moment. As you see at the fig8 amount of generated moment for one period of sea wave is a continuously positive amount and it differs between two positive amounts.

Third advantage of EPEW is that it`s WEC system is like that it's not float on the sea. This makes it possible to absorb all energy of sea waves.

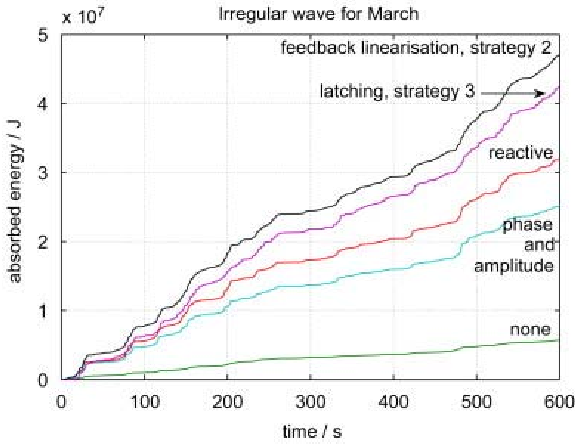

Fig. 10. Evolution of absorbed wave energy with time by Archimedes Wave Swing [4].

RMS moment generated by EPEW for one period in the ideal wave condition is equal to the $1.24P_0 \times x_0 \times y_0 \times R_0$. For comparison, figure of moment of Pelamis wave energy converter is shown in fig11[2]. This advantage (generating positive moment) make it possible to use EPEW like as a motive force for generators.

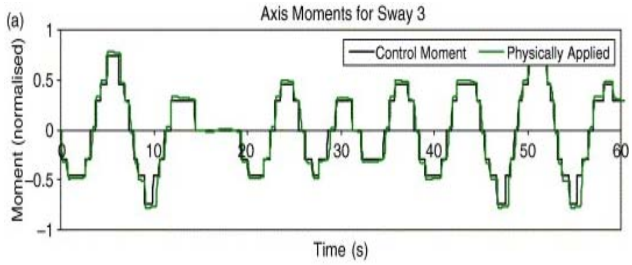

Fig. 11. Moment plot of simulation output for the Pelamis[2].

In other apparatus (by buoy WEC) absorbing all energy of sea wave is not possible for two reasons. First one is that, most of these apparatuses WEC, absorbs wave energy in one or two dimension, but EPEW absorbs wave energy in three dimension. The second one is that in a buoy WEC convertor if we want to absorb more energy from wave we have to use more pressure in WEC (buoy) and it make WEC to drown in wave or not move with wave correctly.

4. Conclusion

A new mechanical wave convertor designed which can converts sea wave to continuously crank shaft motive force and will be used in producing AC electricity from sea waves. This new apparatus;

- Is consist of a new WEC that is not float on the sea level.
- Absorbs continuesly (smooth) energy from sea waves.
- Converts wave energy to a positive crank shaft moment.
- Contact with wave in three dimension.
- Can be used along of sea shore for converting huge energy from waves.
- Can be used in ships and sea crafts and oil exploitation platforms.

- Can absorb wind energy and waterfall energy beside wave energy.

5. References

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