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DEEP OCEAN WAVE ENERGY SYSTEMS: EXPERIMENTAL INVESTIGATIONS

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Abstract:

Deepwater offshore structures have access to very powerful ocean waves by virtue of their location and site condition. Should the energy possessed by these waves be harnessed, it can be one of the popular green energy systems. Present study aims at the design and development of a new device, which can become a component of the offshore semisubmersible platform to produce electricity that is required for its operations, partially. Few wave energy devices are developed in the recent past; commonness amongst all is that they harness heave, or surge energy of the wave impact. In the present study, heave energy of the buoy is converted to mechanical work by deploying hydraulic cylinders and a motor. The experimental studies showed a few limitations in terms of its operational sea states; device needs to be parked under rough weather. The generated power from the waves will be utilized in the semi-submersible platform for deep-sea mining applications. Applicability is limited to calm sea state and deepwater conditions.

Keywords: Tension leg platform , wave energy, float, wave power, deep ocean energy, lever tuned mass damper, multi tuned mass damper, mass ratio

1. Introduction

Wave energy is captured directly from surface waves or from pressure fluctuations below the surface. If suitable devices are developed to capture offshore wave energy, it can supply power to partially or fully meet the energy demand of these offshore structures and thereby reduce operational cost (Chandrasekaran and Deepak, 2013, Emmanuel et al., 2008). An important fact is that the average wave power is cyclic; energy level in winter is about six times higher than that in summer (Antonio, 2010, Falco, 2009). In terms of power potential, offshore locations are more prosperous than shoreline locations. However, these devices have more difficult conditions to contend with (Al Habaibeh et al., 2010, McCabe et al., 2006, Vincente et al., 2009). Shoreline technologies have the benefit of easy access for maintenance. Offshore devices are, in most cases, more difficult to access (Bostrom et al., 2009, Falnes, 2007). Improving reliability and accessibility are therefore important considerations for the multitude of devices in the commercial development (Demetrio et al., 1980). Floating structures are highly influenced by extreme waves and the design should remain robust to cater to operational sea states (Chandrasekaran and Yuvraj, 2013). Shoreline wave energy is limited by fewer potential sites and has high installation costs (Amarkartjik et al., 2012, Pizer, 1993). Their deployment costs are very high due to large economy scale of such projects (David et al., 2010). On the other hand, average unit capacity is generally higher for offshore devices as these individual devices can be very effective (Chandrasekaran and Harender, 2010, 2102). Wave energy is the most assuring natural energy resource that is gaining its thrust in the recent years. Successful attempts are made by several researchers to harness wave energy by heave, surge and sway motion of the devices (Vantorre et al., 2004, Waters et al., 2007, Nune, 2011). However, no successful commercial model is launched until date leaving this domain as a research potential. Present study evaluates the technical feasibility and performance characteristics of a newly proposed Deep Ocean Wave Energy Converter (DOWEC) that converts wave energy into electrical energy; principle is based on mechanical type power take-off mechanism.

2. Deep Ocean Wave Energy Converter System (DOWEC)

Conversion is a combination of mechanical and electrical systems. Overall assembly of the DOWEC is mounted on the deck of the platform while all of its degrees-of-freedoms are restrained. Conceptual design of the proposed DOWEC is shown in Fig.1 while the experimental set up for the proposed design is shown in Fig. 2.

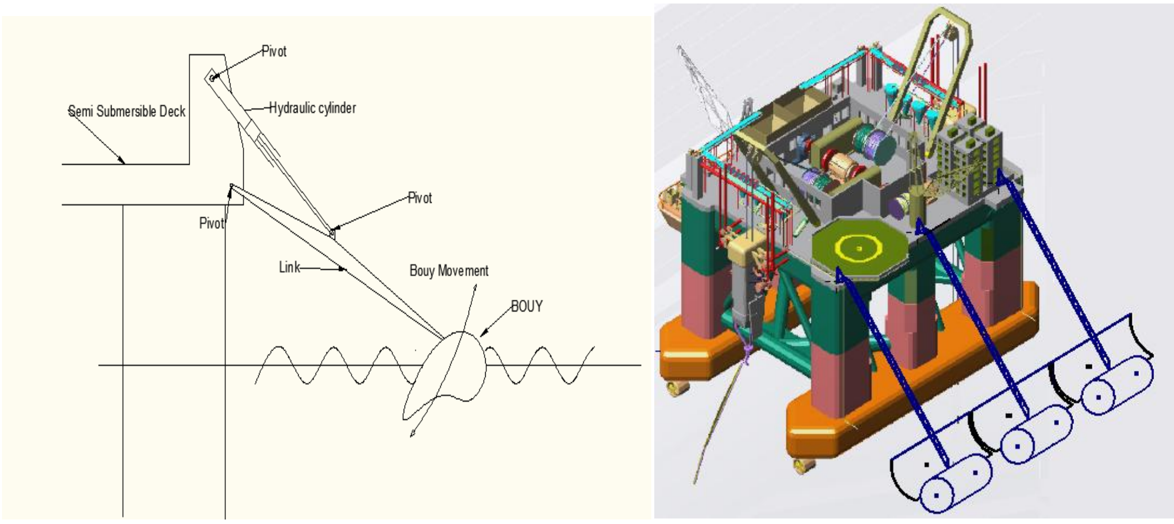

Fig. 1: Proposed deep ocean wave energy system (concept)

Fig. 2: Scaled model of DOWEC

Proposed device is designed to harness power through both the mechanical and hydraulic power take-off mechanisms. When the buoy moves in heave degree-of-freedom, piston moves inwards (and outwards) compressing (and expanding) the liquid in the hydraulic cylinder. Compressed fluid drives a hydraulic motor, which is coupled to the generator to produce electricity. Appropriate RPM multipliers are used to enhance speed of the power shaft. Fins are attached to the buoy to increase energy capture from the waves. To prevent damage during very high waves, the buoy is either arrested in a position above water or sunk under water. During the experimental investigations on the scaled model of DOWEC, regular waves are generated by the reciprocating piston-type wave maker. Power take-off is initiated by heave displacement of the buoy. Apparent weight of the buoy is reduced and displaced due to the Archimedes principle, which in turn produces oscillatory motion of the

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lever arm. Other end of the lever arm is attached to the counter weight. Lever arm is pivoted to the gearbox, which converts the oscillatory motion of the lever arm to the unidirectional rotational motion. Rotary flywheel restores the energy regardless of the input due to its high moment of inertia. RPM produced by the flywheel is supplied to the DC generator through the shaft coupled to the generator. Load is connected across the generator, which identifies the presence of electrical energy when the bulb glows. External measuring components such as power analyser and rpm sensors are used to detect the power and the rpm generated by the set up, respectively. Experiments are conducted for various many parameters namely: i) degree of inclination of the buoy; ii) wave height; iii) time duration; and iv) different lever arm distances.

3. Conceptual Design

3.1 Oscillating arm assembly

An oscillating arm consists of a straight frame is pivoted at its middle. A non-floating body is suspended at one end by means of a steel wire/rope while a counter mass assembly is attached to the other end. In the present study, water-filled steel container is used as a non-floating object and the metal plates are used as the counter mass. Parameters of the mechanical design are given in Table 1.

Table 1: Mechanical design configurations

Mechanical Parameters	**Specifications**
Buoy length	1.5 m
Buoy weight + weight inside the buoy	100kg + 65kg
Lever length	2.7 m
Counter weight	45 kg
Gear type	Spur gear
No of holes in the buoy	24 Nos.
Angle between two holes	8^0

Table 2: Design parameters of the gear box

Component/Parameter	**Specification**
Input gear module	2.5 mm
Gear face width	25 mm
UD gearbox speed ratio	9
Step-up gearbox speed ratio	12
Arm stroke angle (Max)	±25º from mean level

3.2 Design of unidirectional gearbox

There are different methods to convert both the positive and negative directional rotation into a continuous unidirectional rotation. Proposed unidirectional gearbox is also one amongst the standard designs that provides energy in the form of continuous unidirectional rotation from the alternatively rotating arm of the shaft. Unidirectional gearbox has input and output gears; output gear provides a continuous rotation to further conversion. It is designed to drive a permanent magnet DC dynamo with a rated speed of about 600 rpm. Configurations of the dynamo are chosen by considering the resonance condition of the oscillating arm with a counter mass of about 50 kg. Gears are designed for the expected load and for a factor of safety of 2. Table 2 shows the summary of the design parameters of the gearbox.

3.3 Step-up gearbox

As frequency of ocean waves is lesser, speed of rotation from the unidirectional gearbox is expected to be significantly lower than the value that is required by the generator. Hence, a step-up gearbox is coupled to the unidirectional gearbox for increasing the speed of rotation. Step-up gearbox is designed to drive a permanent magnet DC dynamo with a rated speed of about 600 rpm.

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3.4 Design of flywheel

Ware harnessed by the partially-submerged, horizontal cylindrical floating buoy with the fin, through the oscillatory motion of the arm. Due to this oscillatory motion, arm stalls at its maximum positive and negative extremes. Therefore, power generation is not successful at these positions of the rotating arm. This discontinuous flow of power is rectified by providing a flywheel to drive the Power Take-off Mechanism (PTO). Table 3 shows the design parameters of the flywheel.

Table 3: Flywheel parameters

Parameter	**Specification**
Flywheel Mass	16 kg
Maximum Diameter	300 mm
Face Width	40 mm
Maximum RPM estimated	600
Material	Steel

3.5 Permanent magnet DC generator

Current existing DC Generator consists of permanent magnet, which forms the stator of the machine. This converts the mechanical energy into electrical energy by the principle of electromagnetic induction. A permanent magnet DC Generator relies on permanent magnets to provide the magnetic field against which the rotor field interacts to produce torque. Compensating windings, in series with the armature are used in large generators to improve commutation under load. Energy conversion in the generator is based on the principle of the production of dynamically induced emf. Specifications of the DC generator are given in Table 4.

Table 4: Existing DC Generator Specification

Parameters	**Values**
Kw/h	0.25
Voltage	24
RPM	600
Amps	8
Insulation	Class-E
Type	80
Connection	PMDC
Rating	S

4. Results and Discussion

Responses of the device for varying parameters are presented. Figs. 3-6 show the superposition of the variation of mechanical power of the device for two different arm lengths of 1.7 m and 1m, respectively; for 0.3m wave height and 3 s wave period, plots are drawn for 0°,16°,32° and 48° respectively. It is seen that the mechanical power of the output shaft is maximum for the increased lever arm of 1.7 m in comparison to that of the response at 1 m, for all the cases considered in the study. Table 5 shows the comparison of the mechanical power and efficiency of the device for different cases considered in the present study. It is seen from the table that the period at which the maximum power generated is reduced for shorter arm length. For the increased angle of rotation of the buoy from 0 to 48°, average power decreases with the decrease in the arm length. The device showed the maximum efficiency of 21.4% for 1.7 m arm length at 32° angle of rotation of the buoy.

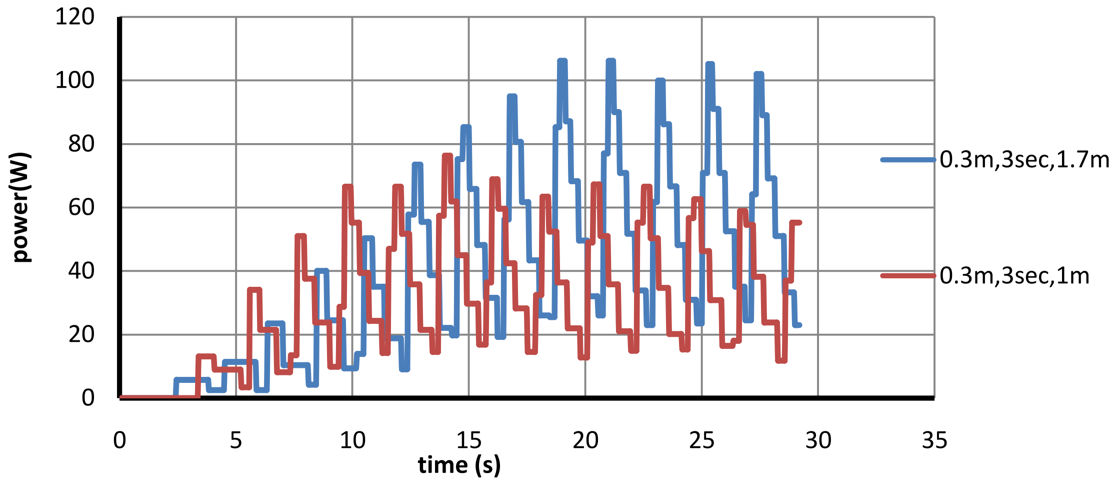

Fig. 3: Variation of mechanical power (0°)

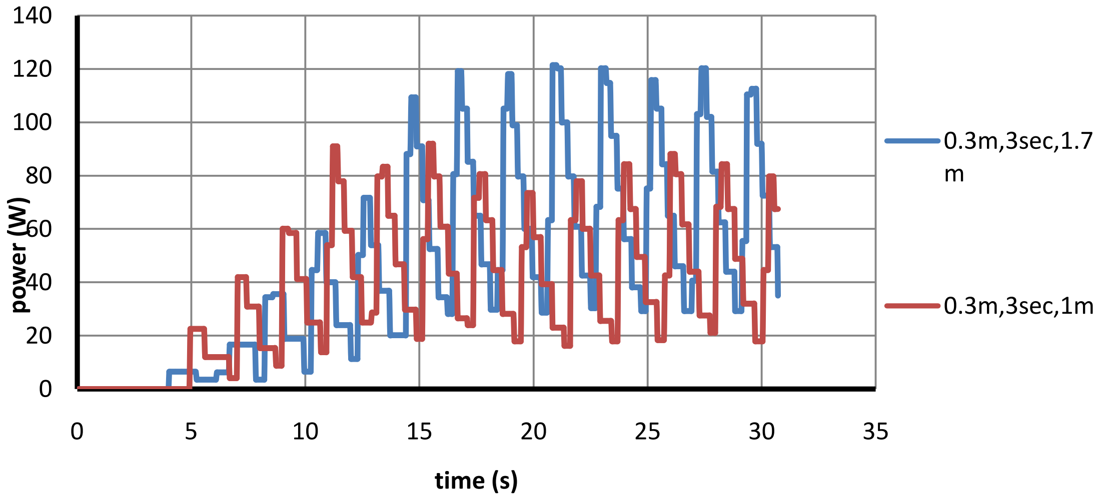

Fig. 4: Variation of mechanical power (16°)

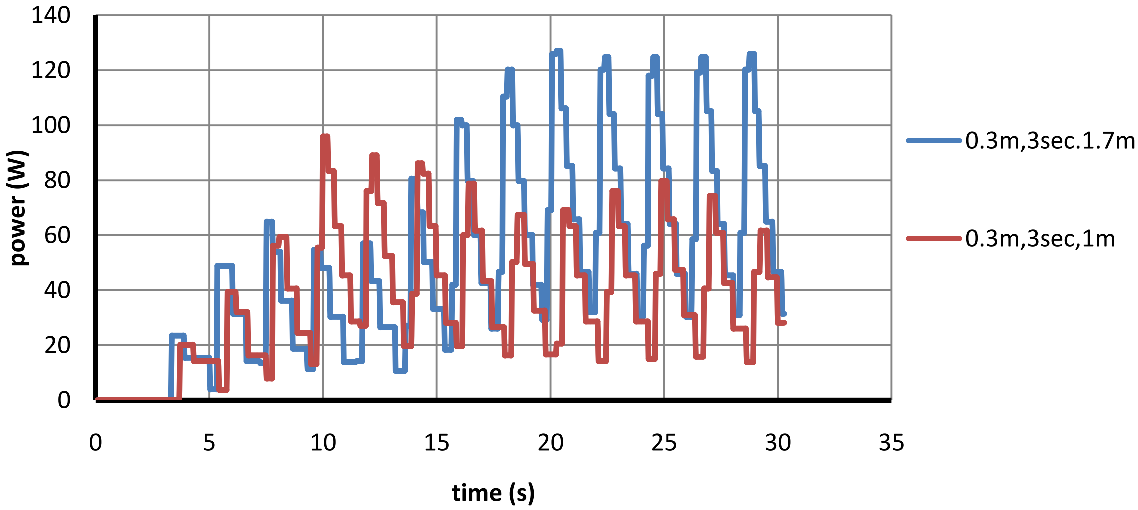

Fig. 5: Variation of mechanical power (32°)

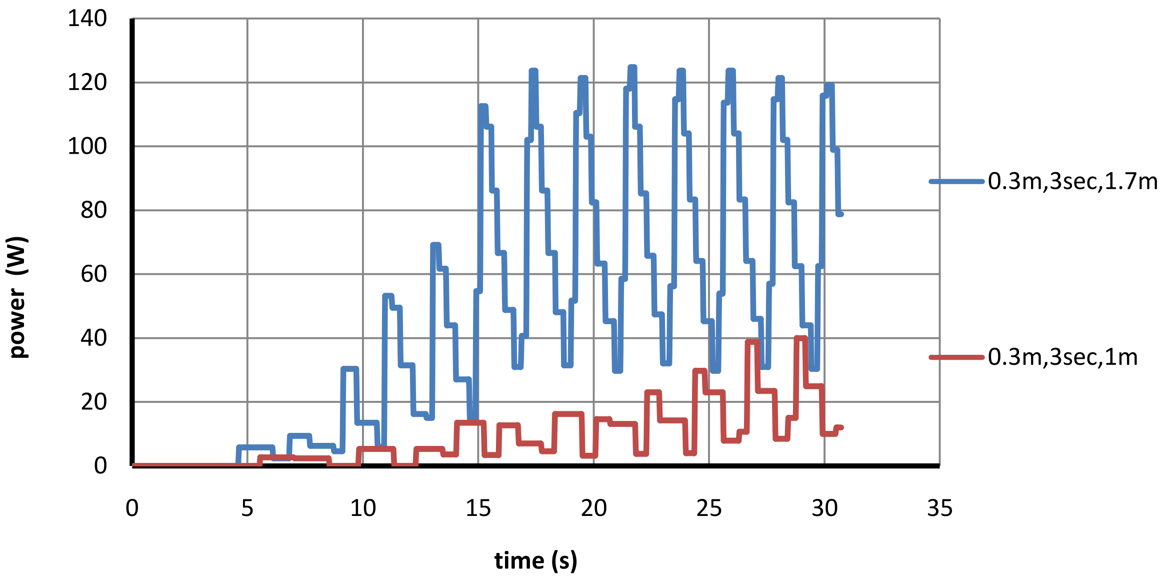

Fig. 6: Variation of mechanical power (48°)

Table 5: Power and Efficiency for angles of rotation of the buoy

Degrees of inclination	Average Power	Efficiency
0°		
0.3,3 sec,1.7m	36.99	14.32
0.3,3 sec,1.m	29.79	11.53
0.27,3 sec,1.7m	33.49	15.99
0.27,3 sec,1 m	19.55	9.33
0.24,3 sec,1.7m	27.89	16.85
0.24,3 sec,1 m	12.73	7.69
16°		
0.3,3 sec,1.7m	45.04	17.44
0.3,3 sec,1 m	36.43	14.10
0.27,3 sec,1.7m	40.36	19.27
0.27,3 sec,1 m	30.07	14.03
0.24,3 sec,1.7m	26.52	16.02
0.24,3 sec,1 m	24.13	14.58
32°		
0.3,3 sec,1.7m	49.13	19.02
0.3,3 sec,1 m	35.74	13.84
0.27,3 sec,1.7m	44.83	21.40
0.27,3 sec,1 m	23.048	11.21
0.24,3 sec,1.7m	32.98	19.89
0.24,3 sec,1 m	22.14	13.37
48°		
0.3,3 sec,1.7m	46.19	17.86
0.3,3 sec,1 m	8.73	13.38
0.27,3 sec,1.7m	35.44	16.92
0.27,3 sec,1m	19.19	9.16
0.24,3 sec,1.7m	31.03	18.75
0.24,3 sec,1 m	12.66	7.65

5. Conclusions

Scaled model of a newly proposed deepwater wave energy converter is experimentally investigated for different sea states. Arm length of rotating shaft and the angle of rotation of the buoy are varied during the study and results are drawn. The paper also presented the detailed design parameters of the said device, which is addressing the critical design characteristics. Based on the studies conducted, it is seen that the mechanical power of the output shaft is maximum for the increased lever arm of 1.7 m in comparison to that of 1 m, for all the cases considered in the study. It is also seen that the period at which the maximum power generated is reduced for shorter arm length. For the increased angle of rotation of the buoy from 0 to 48°, the average power decreases with the decrease in the arm length. The device showed the maximum efficiency of 21.4% for 1.7 m arm length at 32° angle of rotation of the buoy. The presented results of the experimental investigations and the design methodology of the newly developed wave energy converter shall be seen as a prime-facie to the innovative development of wave energy devices. The design is to suffice for operational sea states. However, during rough weather, the buoy is either arrested in a position above water or sunk under water to protect the damage of the device.

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