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A Novel, Cost-effective Design to Harness Ocean Energy in the Developing Countries

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Abstract**—**The world's population continues to grow at a quarter of a million people per day, increasing the consumption of energy. This has made the world to face the problem of energy crisis now days. In response to the energy crisis, the principles of renewable energy gained popularity. There are much advancement made in developing the wind and solar energy farms across the world. These energy farms are not enough to meet the energy requirement of world. This has attracted investors to procure new sources of energy to be substituted. Among these sources, extraction of energy from the waves is considered as best option. The world oceans contain enough energy to meet the requirement of world. Significant advancements in design and technology are being made to make waves as a continuous source of energy. One major hurdle in launching wave energy devices in a developing country like Pakistan is the initial cost. A simple, reliable and cost effective wave energy converter (*WEC*) is required to meet the nation’s energy need. This paper will present a novel design proposed by team *SAS* for harnessing wave energy. This paper has three major sections. The first section will give a brief and concise view of ocean wave creation, propagation and the energy carried by them. The second section will explain the designing of *SAS-2*. A gear chain mechanism is used for transferring the energy from the buoy to a rotary generator. The third section will explain the manufacturing of scaled down model for *SAS-2* .Many modifications are made in the trouble shooting stage. The design of *SAS-2* is simple and very less maintenance is required. *SAS-2* is producing electricity at Clifton. The initial cost of *SAS-2* is very low. This has proved *SAS-2* as one of the cost effective and reliable source of harnessing wave energy for developing countries.

Keywords**—**Clean Energy, Wave energy

I. Introduction

DESPITE technological advancement in the petroleum extraction, discovery rates of new oil reserves are falling every day. The world is using its remaining oil reserves at a prodigious rate. One reason for the increased demand of oil is the gradual increase in world population. The huge burning of fossil fuels has introduced the world with a new problem of global warming as well.

The need for clean and continuous source of energy has emerged the need to explore new methods for harnessing energy around the world. There are many wind and solar energy farms built across the world but the problem is still persisting. Oceans cover almost 70% of the earth surface and they contain a tremendous amount of energy. A rough estimate concludes that there is 8,000-80,000TWh/yr or 1-10 TW of wave energy in the entire ocean [1]. This enormous amount of energy is enough to alleviate the problem of energy from the world.

In the last two centuries, inventors have proposed many ideas for utilizing wave energy. The research in this field gained popularity after the oil crisis of 1973. In the same decade Stefan Salter made the most efficient wave energy device. The idea of wave energy lost its strength in early 1980s, when petroleum prices declined. The idea of harnessing wave energy has centralized the world again because now oil crisis came with a threat call of extreme global warming as well. Although developed countries have induced a heavy amount for the development of new projects but the developing countries are still dealing with their economic crisis.

Now days, Pakistan is also facing the problem of energy crisis. The energy crisis in Pakistan results in heavy load shedding. Pakistan has about 1000 km long coastline [2]. The presence of strong waves along the Makran coast predicts the future of wave energy utilization in Pakistan [2]. A rough estimate shows that the wave energy density in some region near the Pakistan coastline is $15kW/m^2$. Although this energy density is very low comparable to other locations in world but still it can solve the problem of power shortage of a big city like Karachi.

This paper intends to provide a brief introduction about wave energy, its importance and in the end a new wave energy device named as *SAS-2* is also presented. *SAS-2* Patent (Patent#149/2011) has been filed in the Intellectual Property Organization (IPO) of Pakistan. It is basically a continuation of work carried out at Pakistan Navy Engineering College, NUST. *SAS-1* is also a successful device and it contains a linear generator. *SAS-1* was a successful device but the results obtained from it were not good because of an inefficient linear generator. *SAS-2* is made to operate in shallow water. It contains a rotary generator. The results obtained from *SAS-2* are very good and also the money invested on it is very low. *SAS-2* has proved itself as a successful cost-effective wave energy converter. *SAS-2* is in its early development stages. It is expected that further research on *SAS-2* will lead this device as one of the successful wave energy conversion device.

II. Ocean Wave Physics

Like other waves, ocean waves are caused by the disturbance in medium. This disturbance is due to the wind blowing over the surface of ocean which transfers energy. This energy transfer could be seen as a hump in the medium. In an ocean instead of water energy is travelling at the speed of wave. In deep sea a resting object moves in a perfect circle. The diameter of the circle is equal to the wave height [3]. Fig. 1 illustrates the wave particle motion in deep water. The circular motion of the particles diminishes near the bottom of sea bed.

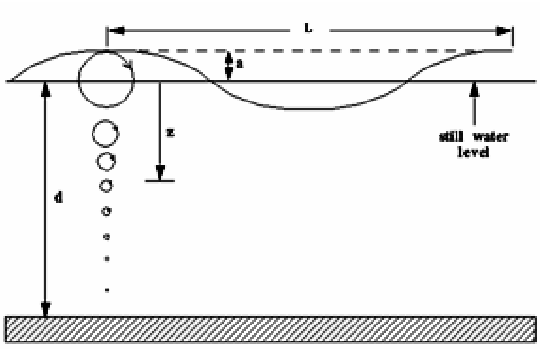

Fig. 1 Wave particle motion in deep water [12]

Wave length determines the size of the orbits of molecules with in a wave and the water depth determines the shape of orbits. In deep sea, wave particles move without the loss of any energy. In shallow water the water particles loses its energy due to the frictional effect with bottom. In this region wave particles move in elliptical form. Just near shore the effect of bottom friction increases so much that the crest starts moving faster than its supporting base and a wave break.

III. Wave Energy

The calculation of wave energy is very important in designing a particular wave energy converter. This factor helps us in determining the size of wave energy converter. One important parameter involve in wave energy calculation is wave velocity.

A. *Wave velocity*

There are two measures for wave velocity. The phase velocity and group velocity. Phase velocity is the velocity of an individual wave [3], [7]. For deep water

$$v = \sqrt{\frac{g\lambda}{2\pi}} \tag{1}$$

Where

$$\lambda = \frac{gT^2}{2\pi} \tag{2}$$

So

$$v = \frac{gT}{2\pi} \tag{3}$$

Where g is the acceleration due to gravity, λ is the wavelength and T is the time period of wave.

The group velocity is the velocity of the packet of waves. In deep water the group velocity is half of the phase velocity.

$$C_{g=}\frac{v}{2} \tag{4}$$

In deep water the velocity of the waves remains constant. As the wave reached in shallow water the velocity of wave start decreasing. In shallow water, the frictional force acting on the wave decreases the wave velocity.

B. *Energy density and Power density*

The energy density of the wave is the mean energy crossing a vertical plane. [5],[6]

$$E_{\ density} = \frac{\rho_{water} g H^2}{8} = \frac{\rho_{water} g A^2}{2} = \frac{\rho_{water} g H_{m0}{}^2}{16} \tag{5}$$

The power density can be found by dividing the energy density by the time period.

$$P_{density} = \frac{E_{density}}{T} = \frac{\rho_{water} g H^2}{8T} = \frac{gA^2\rho_{water}}{2T} \tag{6}$$

C. *Power per meter of wave front*

Power per meter of wave front is determined by multiplying the group velocity with the energy density [5],[6].

$$P_{wavefront} = C_g . E_{density} = \frac{c_g \rho_{water} g H^2}{8} \tag{7}$$

In terms of phase velocity it can be written as:

$$P_{wavefront} = \frac{v\rho_{water} g H^2}{16} \tag{8}$$

By using the relation of phase velocity (7) reduces to

$$P_{wavefront} = \frac{\rho_{water} g^2 T H^2}{32\pi} \tag{9}$$

In term of significant wave height

$$P_{wavefront} = \frac{\rho_{water} g^2 T H_{mo}{}^2}{64\pi} \tag{10}$$

D. *Power intensity (I_z)*

Power flow intensity shows the variation shows the variation in power for the different value of depth for a single wave [4].

$$I_Z = I(\mathbf{0}).\exp(2kz) \tag{11}$$

Where

$$k = \frac{2\pi}{\lambda} \tag{12}$$

Z is the vertical downward distance from mean surface water level. *I(0)* is the intensity of wind at surface of sea. In deep sea 96% of energy is stored within a range of $-\lambda/4<Z<0$. Hence a *WEC* should be placed inside that range of depth.

IV. Wave Energy Converters

There are many ways to classify wave energy converters (*WEC*). This classification is very important for the basic understanding of *WEC*. *WEC*'s can be classified according to their horizontal extension and orientation.

A. *Point Absorbers*

If the extension is very small as compared to typical wavelength then it is called as point absorber. Fig. 2 illustrates the working principle of point absorber. The buoy moves up and down as the wave passes. This motion could be used to generate electricity by the use of linear generator. As they absorb energy at a point from wave so they are named as point absorbers.

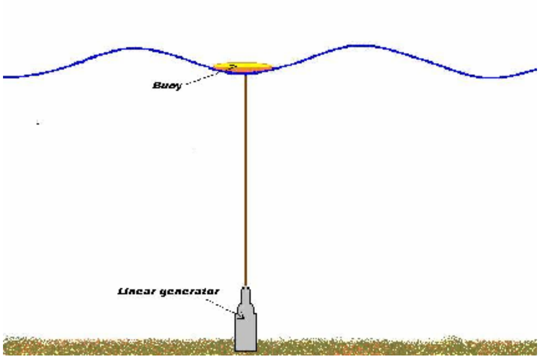

Fig. 2 Concept of point absorber devices [11]

A typical example of point absorber type devices is Archimedes wave swing (*AWS*) as shown in Fig. 3 The *AWS* is fully submerged. It consists of two cylinders. The lower cylinder (silo) is fixed to the seabed while the upper cylinder (floater) moves up and down under the influence of waves .The interior of *AWS* is filled with air. This tends to move the floater into its original position when a wave passes. The relative motion between the two cylinders is used to drive a linear generator.

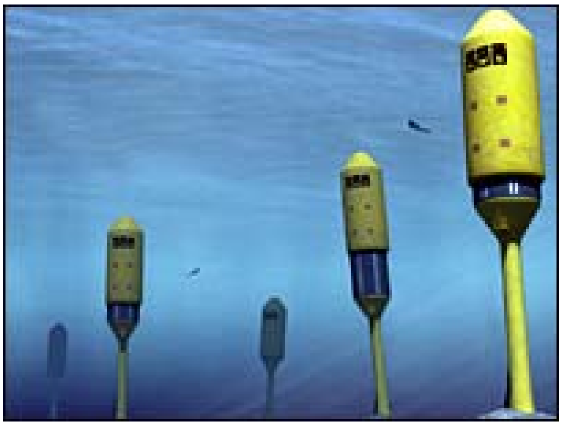

Fig. 3 *AWS* concept [10]

B. *Line Absorbers*

If the horizontal extension is comparable or larger than the wavelength it is called as line absorber [4]. They are further classified into attenuators and terminator type devices.

If a line absorber *WEC* is placed parallel to the direction of the propagation of wave then it is called as attenuator. The world most successful commercially launched *WEC* Pelamis is an example of attenuator type device as shown in Fig.4 The Pelamis is a semi-submerged, articulated structure composed of sections linked by hinged joints. The motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors. The motors drive generators to produce electricity.

Fig. 4 Pelamis WEC

If a line absorber type *WEC* is placed normal to the direction of propagation of wave then it is called as terminator type device. An early example of terminator type device is proposed by Salter Duck as shown in Fig. 5 and it is considered to be the most efficient device.

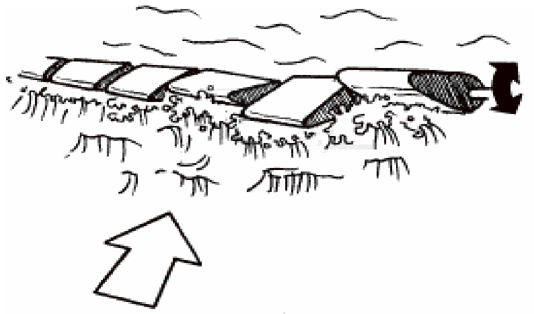

Fig. 5 Concept of Salter Duck *WEC* [8]

SAS-2

Depending upon the need and importance of energy in our daily life, a new *WEC* named as *SAS-2* is made. The aim of *SAS*2 is to generate electricity. Further aim of *SAS-2* is to set a foundation for the *WEC*'s in Pakistan which will further lead us to make a successful *WEC* for Pakistan.

A. *Important Features of SAS-2*

Following are the important features of SAS2

i. It converts both the kinetic and potential energy of waves.
ii. It can convert energy in deep water and shallow water
iii. Highly robust structure
iv. Simple
v. SAS2 is best across the Manora, Gaddani, Clifton, hawks Bay

B. *Concept of SAS-2*

SAS2 is what is sometimes referred to as a 'terminator'. The device is aligned parallel to the wave fronts, at right angles to the principal wave direction, thus 'terminating' the waves as shown in Fig. 9

The device comprises of a float which is slightly submerged in sea water. This float is aligned to the principle wave direction so that it engages with the maximum number of waves. This float will heave with the water particles around it as the wave passes under it. Energy is extracted by in effect damping this motion. This mechanical energy is transferred by a chain drive to the fly wheel. The fly wheel stores the wave energy. A shaft is connected with the fly wheel which is further connected with a rotary generator to produce electricity.

C. *Design of SAS-2*

The process of energy conversion from the waves till the generation of electricity in *SAS-2* is comprises of three steps

1. Front End Conversion

The front end conversion converts the wave into mechanical energy. It is the most important part in designing a *WEC*. An enormous amount of energy is present in waves and if the front end conversion is perfect then it can cover easily the deficiencies in the later conversion mechanism. For front end conversion a float is designed that interacts with the incoming waves. The rear side of the float is connected with an arm which is further pinned at a shaft. This mechanism tends to oscillate the float as the wave interacts.

The weight of the float is decided in way that, within suitable area of application the buoy should be submerged up to $\lambda/4$ of depth so that maximum energy is transferred to the float [9]. λ is the mean wavelength of the waves passing through this region.

Figs. 6 and 7 show the shape of the floats decided at initial stage for comparison. If we consider parallel stream line flow of water coming towards float-1 then they will try to cancel each other effect after collision. In case of float-2 they will become parallel after collision. Hence float-2 is used for the *WEC*.

It is designed as a terminator type device for getting maximum efficiency. So its length is comparable to wavelength.

The final form of the front end conversion mechanism is shown in Fig.8

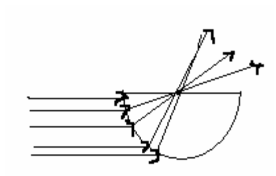

Fig**.** 6 Float-1 for *SAS-2*

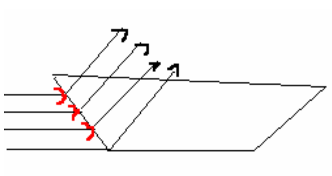

Fig. 7 Float-2 for *SAS-2*

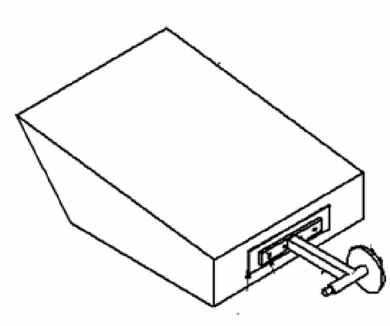

Fig. 8 Float of *SAS-2* connected with arm

2. Intermediate Conversion

The power transmitted by the wave to the float is further converted into rotary motion by a set of chain drives. If mechanical losses are neglected then the power transmission in the sprockets is governed by eq.13. There are three chain drives used in *SAS-2* to obtain the required rpm and torque for the generator.

$$\tau_1 \omega_1 = \tau_2 \omega_2 \tag{13}$$

Here τ_1, τ_2 is the torque and ω_1, ω_2 is the angular velocity of drive and driven sprocket gears respectively.

A flywheel is used to store energy. This stored energy is used to drive the generator continuously at constant rpm. Eq.14 shows the energy stored in a flywheel .A 46 kg flywheel is used in *SAS-2*.Flywheel designing parameters are adjusted after monitoring the time between two wave crest.

$$E_k = \frac{I_f \omega_f^2}{2} \tag{14}$$

I_f is the polar moment of inertia of flywheel and ω_f is the angular velocity of flywheel.

3. Electromechanical conversion

For the electromechanical conversion in *SAS-2*, a DC geared generator is used. It has an in built gearbox so that less rpm is required for the generator. The generator shaft is driven by a chain drive. This chain drive connects the generator shaft with the flywheel so that the generator runs with a smooth and continuous rpm.

D. *Structure of SAS-2*

A simple robust structure is used to hold *SAS-2*. The base of the structure is fixed in sea bed. The fixed structure provides a rigid support for the float to stand against waves. Hence maximum energy is transferred to the float as there is no relative motion in between the structure and float.

E. *Complete assembly of SAS-2*

The complete assembly of *SAS-2* is shown in fig.9 The direction of propagation of waves is normal to the float motion. All the assembly is mounted on a fixed standing structure. This complete assembly is placed in sea at a depth where the float and the mean surface level of water (*SWL*) become parallel.

V. RESULTS OF *SAS-2*

The testing of SAS2 is done at various stages. At first float was fabricated and tested individually to check it response against the incoming waves. Then the complete assembly was tested. The results obtained at every stage are further used in making some modifications. These results are compared with the help of energy stored in flywheel. Table 1 relates the results obtained at different stages of test.

TABLE I
RESULTS OF *SAS-2*

	1st Test	2nd Test	3rd Test
Average Rpm of flywheel	60	100	165
energy stored in the flywheel	70 J	191.9	522.47 J

VI. CONCLUSION

This paper gave an overview of the work done by team *SAS* in designing a successful *WEC*. Its success on such a small scale has proved it as a successful *WEC*. The design of *SAS-2* is in its early stages. It is expected that small modifications and further research will lead *SAS-2* on commercial level.

NOMENCLATURE

WEC	Wave energy converter
OWC	Oscillating water column
AWS	Archimedes Wave Swing
SAS	*SAS* is the name of our group
SWL	mean seawater level (surface)
E density	wave energy density
E wave front	Energy per meter wave front
P density	wave power density
P wave front	Power per meter wave front
h	Sea depth
Ω	wave frequency
λ or L	wavelength
ρ water	Sea water density
G	gravitational constant
A	wave amplitude
H	wave height
T	wave period
V	Phase velocity
Cg	Group velocity
Hm0	Significant wave height

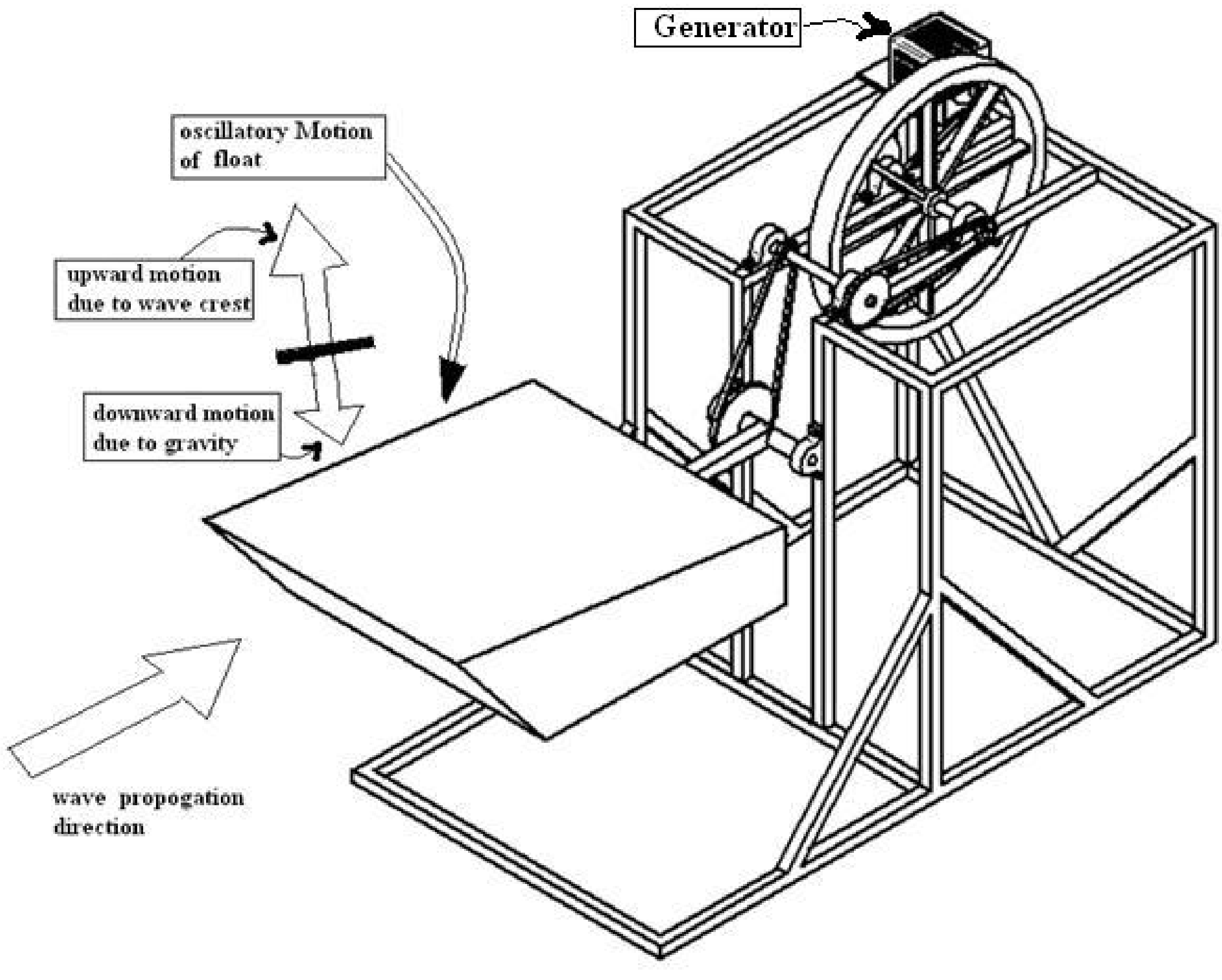

Fig. 9 Complete assembly of *SAS-2*

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REFERENCES

[1] Richard Boud, "Status and Research and Development Priorities, Wave and Marine Accessed Energy," UK Dept. of Trade and Industry (DTI), DTI Report # FES-R-132, AEAT Report # AEAT/ENV/1054, United Kingdom, 2003.

[2] N. A. Zaigham, Z. A. Nayyar, "prospects of renewable energy sources in Pakistan", Proceedings of comsats conference 2004 on renewable energy technologies & sustainable development, 2005.

[3] T. Garrison, "Oceanography, An invitation to marine sciences", Brooks/Col Cengage Learning, 2009.

[4] J. Falnes "A review of wave-energy extraction", p.p. 185–201, Marine structures, vol.20, pp 185-201, Elsevier, 2007.

[5] M. E. McCormick, "Ocean wave energy conversion", Dover, 2007

[6] A. Muetze, J. G. Vining, "Ocean wave energy conversion–a survey", electrical and computer engineering department, IEEE, 2006.

[7] T. K.A. Brekken, A. v. Jouanne, H. Y. Han, "Ocean wave energy overview and research at Oregon State University", unpublished.

[8] http://earthsci.org/mineral/energy/wavpwr/wavepwr.html

[9] S. Ayub, S.N Danish, S.R. Qureshi, S.R. Rehman , A. Ahmed, "A novel approach to harness ocean energy", Proceedings of the 8th international conference on applied sciences and technology, Islamabad, Pakistan, 10-13 January, 2011.

[10] http://news.bbc.co.uk/2/hi/uk_news/scotland/highlands_and_islands/6749709.stm

[11] http://commons.wikimedia.org/wiki/File:Point_absorber.JPG

[12] http://scubageek.com/articles/wwwparticle.html

[13] S.Ayub, S.N Danish "Patent # 149/2011, A Wave energy Converter", Intellectual Property Organization, Pakistan.