Feasibility Study of Ocean Wave of the Bay of Bengal to Generate Electricity as a Renewable Energy with a Proposed Design of Energy Conversion System

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Abstract- In this paper the results of feasibility study to generate electrical energy from waves of the Bay of Bengal have been discussed. The wave resource assessment, economic conditions, challenges and the cost estimation for power generation are also described. Calculation of Wave energy and an analysis of energy fluctuation at various months of different consecutive years are presented. It is observed that, waves have travelled with a lot of energy from April to October and a considerable amount of energy at November to March in the Bay of Bengal at Cox's Bazar, Chittagong. The energy is wave dominated. Due to availability of generated wave, it is possible to generate Power with full pace from April to October and considerable amount can be generated at rest of the months. In the circumstances research on renewable energy is very important to mitigate the increasing power demand and a contribution to reduce global warming. Moreover, a new design methodology of ocean wave energy conversion is described. This design is focused on the velocity of wave and it will captured energy from wave as a thrust force which will be used to the conversion of electrical energy as per design presented. An option has been adopted for hybridization from various renewable sources of that device which can reduces the cost of device and increase the power generation has also been described. Proposed method could be applicable to convert the energy from ocean wave all over the world.

Keywords- Renewable Energy, Ocean Wave, Feasibility Study, Bay of Bengal, Energy Conversion.

1. Introduction

Electricity is basic necessity and the most important thing of any country. In according to the circumstance of Bangladesh, most of the populations are deprived from such facilities for the crisis of electricity. Now-a-days power generations from renewable sources are most popular all over the world. Every country has effort to generate power from renewable energy on account of its availability. Sustainable or renewable energy comes from natural resources like sunlight, wind, rain, Geo thermal, Hydropower, Biomass, Tidal power and Wave power. Ocean is one of the largest reservoir of wave energy. However, Ocean wave is possessed two kinds of energy such as kinetic energy and potential energy. Bangladesh has a few of large costal area which is very suitable to implement this project. The theoretical ocean wave energy is estimated 8000-80000 TWh/year [1]. Considering the recoverable energy and if the efficient conversion systems are utilized, the annual quantity can even reach 2000TWh [2]. Variability in several time-scales is the main disadvantage of the wave energy which includes wave to wave, with sea state, and month to month variability [3]. It is researched [4] that the wave energy contains 15-20 times energy than wind or solar energy per square meter.

This research provides an overview of the energy conversion of ocean waves generated in the Bay of Bengal with the wave energy extraction process. So, the specific objective of this project is to develop a model/prototype experimentally to produce electrical energy by using ocean (costal) wave. Then, the areas of further research are identified. In present situation the common matter of our country is load shedding, because of high demand of electricity than production. It is impossible to develop a country as modern without electricity. It seems that, although its initial implementation cost is high but there is no cost except maintenance after establishment of this project. So this research is very important for the power generation from renewable energy source like tidal wave for our country where large costal area is available. From this project it can be concluded that the great deal of energy can be produced using the wave energy conversion method.

The above project can prove itself to be a very competent one for today's energy crisis and our fight against environment pollution. Spatially in a country like ours this project can save a lot of money and time by saving energy and providing a high production rate. This can always be more suitable for our less skilled man power as this project is to develop a robust system. This research seeks to predict the investigation of results obtained in the ocean wave energy conversion for the generation of electricity for Bangladesh that has not yet been reported.

2. Characteristics Of Ocean Wave

Waves are described by height and period, with height measured as the difference between trough and crest, and period as the time between successive crests. Maximum area of the world is ocean area which produced huge amount of waves as shown in Fig. 1.The significant wave height is 1.6 times smaller than the individual maximum wave height [5].

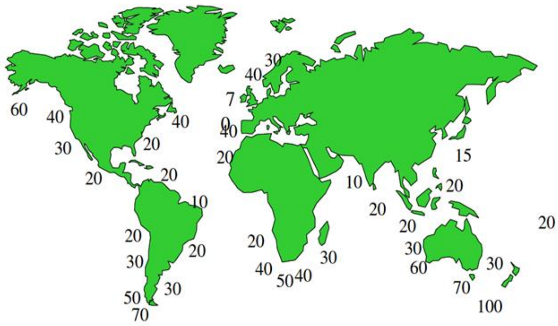

Fig. 1. The scenario of world map with ocean area

Fig.1 shows the ocean area in the world map where the ocean and marginal seas are about 71% of total area of the world [5].

2.1 Alternative Energy Sources of Bangladesh (A Comparison among Energy Type, Energy Density, Predictability, Availability, Potential Sites)

Alternative energy sources according to availability of density are shown in Table 1[6]. Table 2 represent Wave energy Comparisons to other Renewable energy[7].

Table 1. Alternative energy sources according to availability of density [6]

Type of Energy	Energy Density	Predictability	Availability	Potential Sites
Wave Energy	Low to Moderate	Predictable in most sites	80-90%	Extensive but Limited
Combustible Fuels	Very High	Predictable	80-90%	Extensive
Wind	Low	Unpredictable except in limited number of sites	30-45%	Limited
Solar	Low	Unpredictable except in limited number of sites	20-30%	Limited

Table 2. Wave energy Comparisons to other Renewable energy [7]

Issues	OPT Wave power	Solar	Wind
Energy density and predictability	High	Low	Low
Availability	90%	20%-30%	20%-30%
Potential Sites	Virtually Unlimited	Limited	Very Limited
Average power Output per Plant	Scalable to 100+MW	Scaleable to 5MW	Scaleable to 30MW
Environmental issues	None	Visual Pollution	Noise and Visual Pollution
Fuel	None	None	None
Power Station Cost/kW		$10,000	$3,000
Secondary	$6,200	$4,500	$1,000
Primary	$2,300		

2.2 Costing for the Power Generation from the Obtained Wave Energy

These cost estimates are for a small scale project in Alaska collected from [8] and presented in Table 3.

Table 3. Costing For Power Generation from Obtained Wave Energy [8]

Unit	1		2		4		8	
Costing	K$ USD	$/MW	K$ USD	$/MW	K$ USD	$/MW	K$ USD	$/MW
Capital Cost (1)	$8,89	$13.7	$15,097	$11.6	$26,237	$10.1	$48,370	$8.9
Annualized OPEX (1)	$330	$0.51	$510	$0.39	$810	$0.31	$1,400	$0.27
Rated Power	650	kW	1,300	kW	2,600	kW	5.200	kW
Capacity Factor	48	%	48	%	48	%	48	%
Availability	95	%	95	%	95	%	95	%
Annual Energy Output	2596	MWh	5193	MWh	10,386	MWh	20,772	MWh
Cost of Electricity (2010 $)	45.1	c/kWh	38.0	c/kWh	32.3	c/kWh	28.4	c/kWh

These cost estimates are for a small scale project in Alaska and not representative of future costs.

Advantages of different wave energy systems are described in previous studies are presented in [9-12].

3. Wave of Bay of Bengal

Graphical Representation of Wave of Bay of Bengal

The graphs shown below are the significant wave height (m) of Bay of Bengal at different years. The data of wave height is a average value for every day. The data is collected at Longitude 92 East and Latitude at 21 North. The data collection time starts from 717 points which is gradually increases by adding one minute after every point. Where

VARIABLE: Significant Wave height (m)
DATA SET: Significant Wave height Map - Based on NRT merged data
FILENAME:dataset-nrt-global-merged-mswh-latlon-switched
FILEPATH:
http://atollaviso.vlandata.cls.fr:41080/thredds/dodsC/
SUBSET : 717 points (TIME)
LONGITUDE: 92E and LATITUDE: 21N

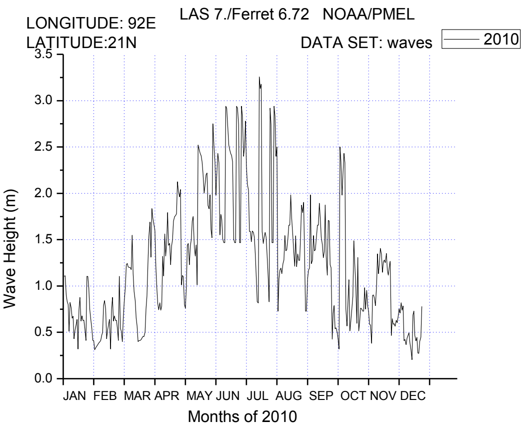

Fig. 2. Significant wave height merged (m) in the year 2010

Fig. 2 provides information about the significant wave height of the Bay of Bengal over the year 2010. There are two basic general trends: downward and upward. As regards the first three month that means January to March the wave heights fluctuated within 0.4 Meter to 1.2 Meter, and the trend was upward. By the way, it is seen that the wave heights fluctuated within 0.8 Meter to 2.8 Meter during the month of April to June but the trend was downward. From July to September the significant wave heights fluctuated abruptly i.e. 0.9 Meter to 3 Meter, but the trend was downward. The last three month of the year 2010 the wave heights are sudden rose and fell at August and finally fluctuated wildly, but the trend was upward. It is noticeable that the significant wave heights are higher at the month of July.

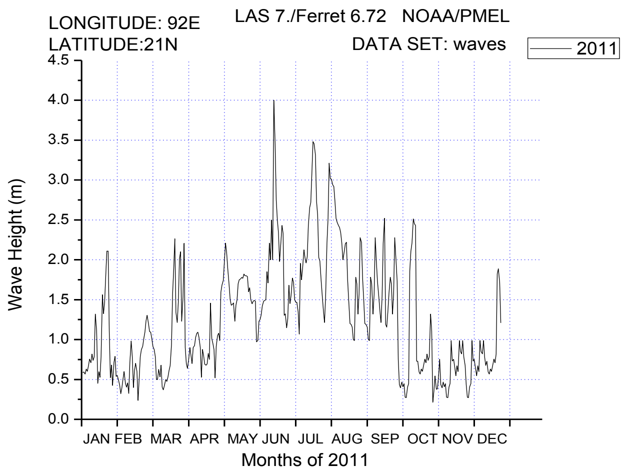

Fig. 3. Significant wave height merged (m) in the year 2011

Fig. 3 provides information about the significant wave height of the Bay of Bengal over the year 2011. There are two basic general trends: downward and upward. As like as the year 2010 there are the wave heights fluctuated wildly, but the trend was upward. It is observed that during the month of January to April the wave height fluctuated within 0.3 to 1.6 Meter. It is also seen that in the month of May to September wave height varied within 1 to 3.5 Meter but the common range of these months is 1 to 2 Meter and rest of the month wave height maintain a lower range that is below the 1 Meter. It is also noticeable that the significant wave heights are higher at the month of June whereas the highest wave heights are found at the month of July in 2010.

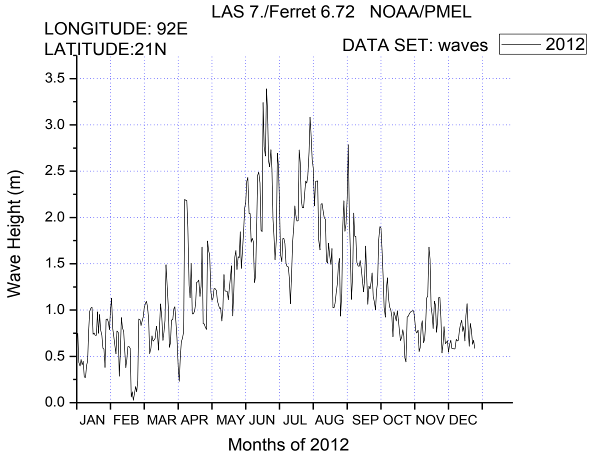

Fig. 4. Significant wave height merged (m) in the year 2012

Fig. 4 provides information about the significant wave height of the Bay of Bengal over the year 2012. The significant wave heights fluctuated wildly over the year 2012, but the trend was downward. The higher wave heights are observed at the month of June which is similar to the year of 2010. It is seen that in the month of January to March fluctuation of wave is regular below the 1 Meter and above the 0.5 Meter. This range is similar for the month of October to December. The month of April to September the wave height fluctuation trend is approximately same to the previous year.

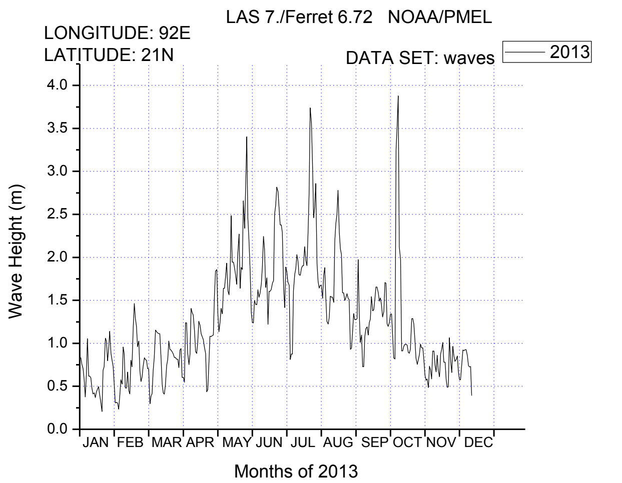

Fig. 5. Significant wave height merged (m) in the year 2013

Fig. 5 provides information about the significant wave height of the Bay of Bengal over the year 2013. The significant wave heights fluctuated wildly over the year 2013, but the trend was downward. The higher wave heights are observed at the month of July. Another highest significant wave height is observed at the month of October which is unpredictable and not rational as compared with the previous years. The characteristic of wave is almost similar to the previous year.

The combination of wave height in the year of 2010, 2011, 2012 and 2013 are presented together in Fig. 6 for the comparison of the wave heights all over the year.

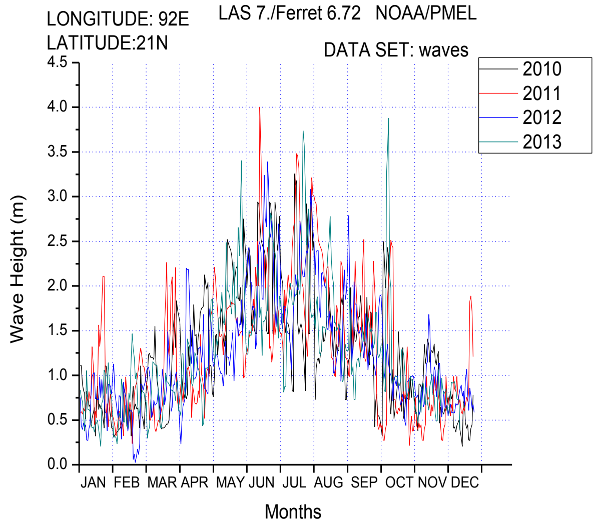

Fig. 6. Combined significant wave height merged (m) in the year 2010, 2011, 2012 and 2013

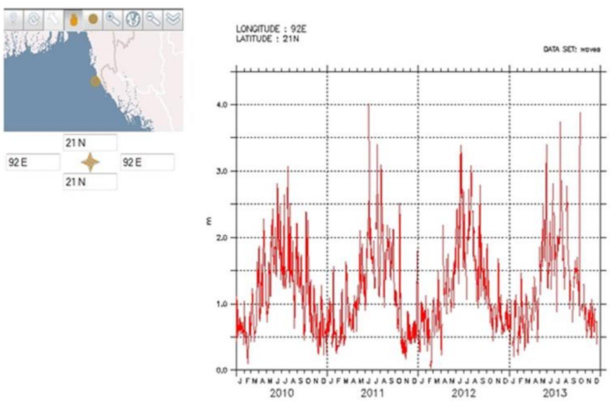

Fig. 7. Significant wave height merged (m)

Fig. 7 deals with the information about the significant wave height trends of the Bay of Bengal over the last four years. The significant wave heights fluctuated wildly over the last four years, but the trend was almost same. It is seen from the graph that the significant wave height are higher at the month of April to October and fluctuate within 0.5 to 1.2 Meter at the month of November to December and January to March. This trend of wave may be for every year.

4. Wave Energy Calculation

It is important to calculate the energy stored in the wave the conversion of wave energy to electrical energy. The following analysis represents the wave energy formula [13]. Nomenclature of wave is presented in Fig. 8.

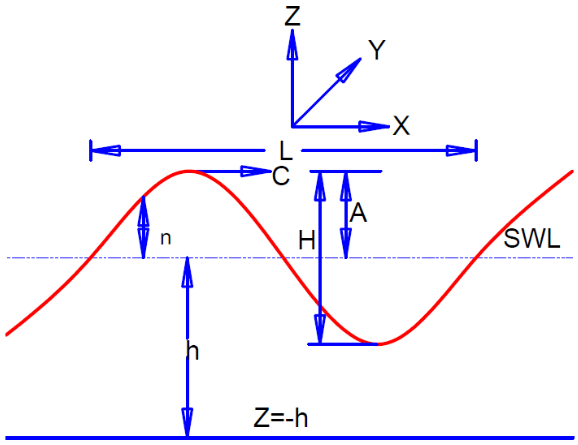

Fig. 8. Nomenclature of Wave

$$E_d = \rho_w g H^2/8\left[j/m^2\right] = \rho_w g A^2/2\left[j/m^2\right] \quad (1)$$

$$P_d = E_d/T = \rho_w g H^2/8T = \rho_w g A^2/2T \quad (2)$$

Eq. (1) shows the energy density of wave. The energy per wave period is the wave's density also presented in Eq. (2).

Where, Mean Seawater Level is SWL,
Wave Energy Density (j/m^2) is E_d
E_{wf}= Energy per meter of Wave front (j/m)
P_d= Density of Wave Power (w/m^2)
P_{wf}= power per meter wave front (w/m)
h= depth below seawater level
ω= wave frequency (rad./sec.)
λ (or L)= wave length (m)
ρ_w= seawater density [1024kg/m^3]
g= gravitational constant [9.81m/s^2]
A= amplitude of wave (m)
H= height of wave (m) [significant wave height]
T= period of wave (s)
C= celerity (m/s) [wave front velocity]

4.1 Wave Front power

A wave resource is typically described in terms of power of wave front per meter. This can be calculated by multiplying the energy density by the wave celerity (wave front velocity).

Where $C = \dfrac{gT}{8\pi}$ (3)

$$P_{wf} = C \times E_d \quad (4)$$

Equation (4) can be written as,

$$P_{wf} = \frac{gT}{8\pi} \times \frac{\rho_w g H^2}{8} = \frac{\rho_w g^2}{64\pi} H_m^2 T \quad (5)$$

Here the water depth is larger than half the wave length.

4.2 Statistic for Wave Power

A wave resource is typically described in terms of power per meter of wave front (or wave crest). This can be calculated by multiplying the energy density by the wave celerity (wave front velocity). This graph constructed by average wave energy density per meter of wave front.

Average wave power density can be calculated as
For January

$$H_{mj} = \sum_{i=0}^{n} H_{mi} \times T_i \left[i = 1, 2, 3, 4......, 31\right] \quad (6)$$

$$P_{aj} = \frac{H_{mj}}{n}\left[n = 31\right] \quad (7)$$

For February

$$H_{mf} = \sum_{i=0}^{n} H_{mi} \times T_i \left[i = 1, 2, 3, 4......, 28\right] \quad (8)$$

$$P_{af} = \frac{H_{mf}}{n}\left[n = 28\right] \quad (9)$$

And so on for the other months.
Where,
H_m=Average significant wave height in a day
T =Time period
n =Number of days in a month
P_a =Power per meter wave front
H_{mj} = Average wave height in the month of January
H_{mf} = Average wave height in the month of February.

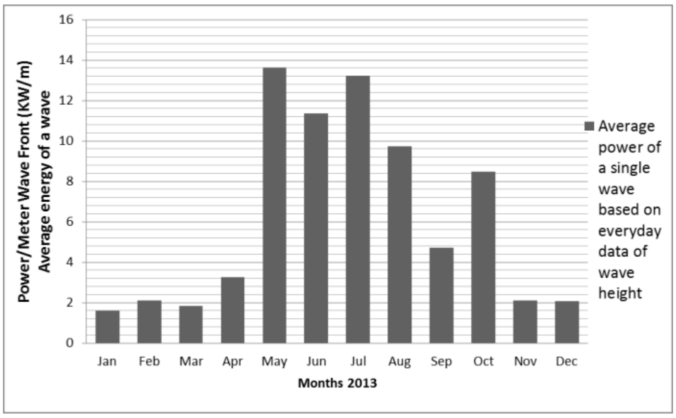

Fig. 9. Average power of a wave based on everyday data of significant wave height in the year of 2013.

Fig.9 provides information about the average energy of wave of the Bay of Bengal at every month over the year 2013. It is observed that during the four months of the beginning of the year means January to April there is no significant change of wave energy. The significant wave energy is observed from May to August whereas the maximum energy of wave can be extracted during the month from May and July. The wave energy of September and October is too much better than November and December.

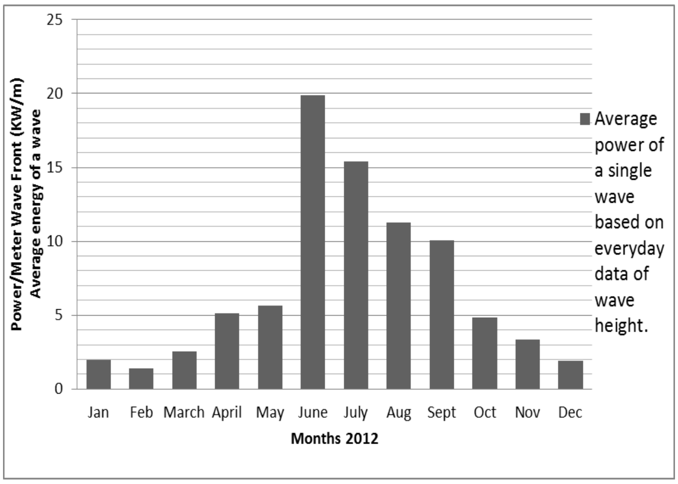

Fig. 10. Average power of a wave based on everyday data of significant wave height in the year of 2012.

The significant wave height of the Bay of Bengal at every month over the year 2012 is shown in Fig. 10. As regards the five months of the beginning of the year that means January to May there is no significant change of wave energy. The significant wave energy is observed at June and July whereas the maximum energy of wave is found at the month of June. The wave energy of September and August is too much better than October, November and December.

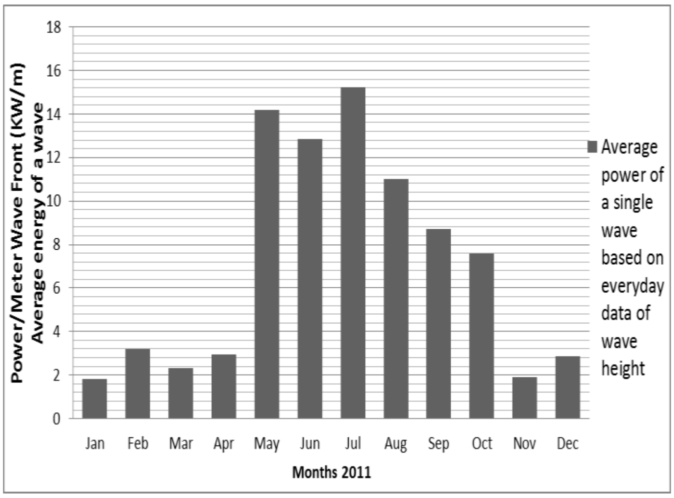

Fig. 11. Average power of a wave based on everyday data of significant wave height in the year of 2011.

Over the year 2011 the wave energy of the Bay of Bengal is presented in Fig. 11. Which show the first four months that means January to April there is no significant change of wave energy. From May to August significant wave energy is observed, whereas at the month of July the maximum energy of wave is founded. The wave energy of September and October is too much better than November and December.

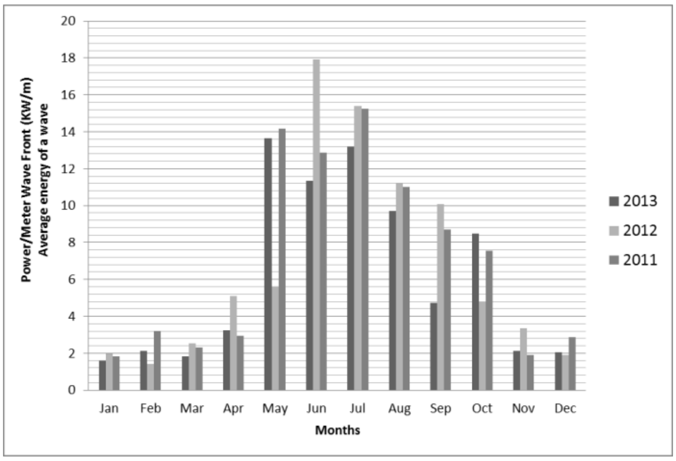

Fig. 12. A comparison of wave power at different months among the year of 2011, 2012 and 2013.

In Fig.12 comparative information about the average energy of wave of the Bay of Bengal over the year 2011, 2012 &2013 are provided. During the first four months means January to April there is no considerable change of wave energy. From May to August significant change of wave energy is observed, whereas at the month of July of these years showing good average wave energy. The wave energy of September and October of presented years is too much better than November and December. It is also seen that the wave energy level are almost same for every year.

5. Methodology of Proposed Design for Energy Conversion

There are hundreds of Ocean wave energy conversion system have been developed and most of these are based on oscillating wave column [14]. Drew et al. [15] published the most recent review on the wave energy conversion technologies.This design focused on wave velocity near the coastal area. An energy collector is used to collect the energy of wave in the form of thrust force. Then it will be concentrated within a line. The energy will send out away through a power transmitting device. The rough environment of ocean can be ignored with the help of this power transmitting device also both safe and effective conversion. A feedback system has been adopted to maintain the position of the energy collector. A motion converting device also designed for converting the linear motion into rotary motion. Finally the rotary motion will convert into electrical power. There is an option for changing design and hybridization.

5.1 Experimental Methods

1) **Wave Power Collection:** A curved plate is used to collect the energy of costal wave. This plate is constructed with some components, such as spring, Plunger, Supports, Shaft, Hanger linkage and Bearing. The curved plate is constructed as shown in Fig.13. This plate is hanged by some linkage and support and the linkage are joints with Bearings. A plunger attached at the end of the shaft. The Bearing is used to move the plate on a rail. This plate can be slide back and forth with the aid of bearing.

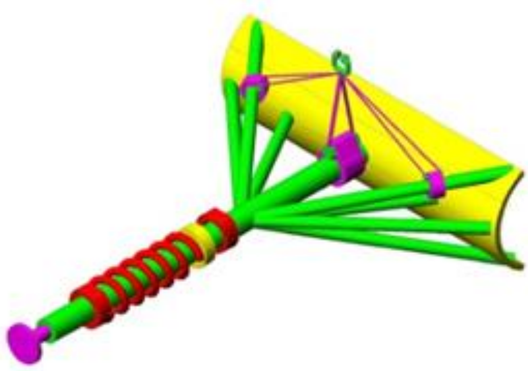

Fig. 13. Wave power collector of proposed conversion system

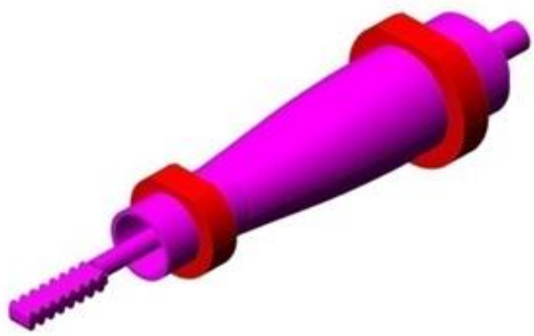

Fig. 14. Power transmission line of proposed conversion system

The curved plate is placed against the costal wave. The costal wave traveled towards the coastal area. When the wave (amplitude) strikes the curved plate it develops a linear motion on the energy collector. Then it will move along the rail in reversed direction.

2) **Feedback System*:*** Simultaneously the spring stored an amount of energy that equal to energy required to move the collector, which is used to back the plate to its initial position when the effect of the wave is disappeared. The plate can move within a limit and spring senses the limit. The plate is always place at its initial position by the spring action.

3) **Energy Transmission Line:** The Energy Transmission line is shown in Fig.14. This is constructed by flexible pipe, incompressible Fluid, Plunger, Connecting rod, Rack gear. The both end of the flexible pipe are joined with two cylinder of different diameter. The cylinder of energy collector side is larger diameter and the cylinder of energy conversion side is comparatively smaller diameter. A plunger, Connecting rod and a Rack gear are joined as a one component. This plunger is placed on the cylinder of motion conversion side and the other plunger which is joined with the shaft of the energy collector is placed to the larger cylinder. When the plate developed a linear motion simultaneously the plunger of larger cylinder move forward that's why the other Plunger of smaller cylinder move same direction due to energy transmitted by a incompressible fluid. At this time the Rack gear moves forward because they are attached. Wave energy converted into mechanical energy.

4) **Motion Conversion System:** The motion conversion system is shown in Fig.15. This system is constructed with a few components, which are Plunger with rack gear, Gear-1, Idle Gear, Piston, Flywheel, Shaft, Ratchet mechanism, Support. The Gear-1 and Flywheel are coupling on a shaft and the Flywheel is coupled with a ratchet mechanism. The Ideal gear placed below the Gear-1. The Gear-1, Rack Gear and Ideal gear are mesh with each other. Ideal gear is free to rotate. It works as a support of Rack. Every component is supported as shown in fig. When the Rack Gear move forward it will develop a rotation on Gear-1 and Ideal gear that's why the Flywheel also developed a rotation due to they are coupled to each other. So the wave energy is converted linear motion to rotary motion. When the plate is returns to its initial position the Rack gear also move backward due to use of incompressible fluid in the power transmission line. When the Rack gear move backward the Gear-1 and Shaft also rotate in opposite direction but the Flywheel is rotated in its initial direction.

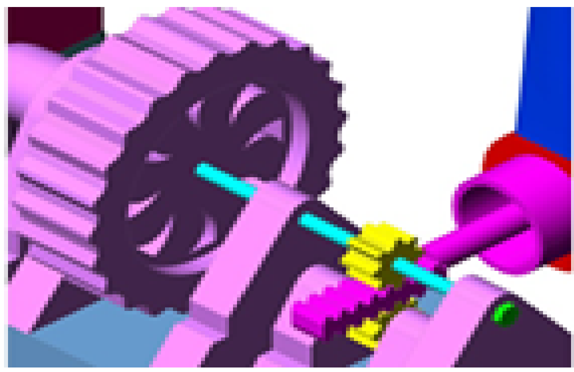

Fig. 15. Gear mechanism of proposed conversion system

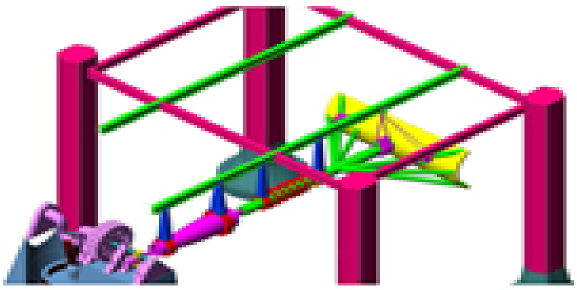

Fig. 16. Schematic diagram of proposed conversion system

5) **Mechanical Energy to Electrical Energy Conversion Unit**: It is well known factor that Flywheel stored energy.

An alternator is connected with the Flywheel. The rotation of Flywheel is transmitted to the alternator through a shaft which will generate electricity. Fig. 16 shows the Schematic diagram of the energy conversion system.

6) **Feature for Change of Design:** The design can be changed in the motion conversion system and mechanical to electrical energy conversion unit. Such as a reciprocating pump can used for add a higher pressure in a fluid. The energized fluid use to form rotational energy by using a Pelton wheel turbine (Impulse Turbine).

7) **Option for Hybridization:** This ocean wave energy converter can hybridize by several renewable energy sources. The renewable energy sources are wind and solar energy. The wind energy is more preferable for hybridization due to availability of wind in coastal area.

6. Conclusions

The increase of power consumption reduces the source of fossil fuel day by day. Bangladesh is a developing country, where most of the power plants are dependent on natural gas. Maximum amount of power is produce by natural gas. The amount of natural gas is limited, but, the amount of reserved gas decreased considerably which will reduce to zero within a few years (short time). As a result it is necessary to reduce the dependency on fossil fuel by the utilization of renewable energy as much as possible. Ocean wave is one of the largest sources of renewable energy. There is limited resource of ocean wave power in the Bay of Bengal at Cox's bazar, Chittagong. The energy is wave dominated, which can be utilized by a recommended technology with a commercial consideration. In the feasibility study it can be concluded that, it is possible to generate Power with full pace from April to October and considerable amount can be generated at the rest of the months. Moreover, a new experimental design methodology of ocean wave energy conversion system is described in this research. An option has been adopted for hybridization from various renewable sources of that device which can reduces the cost of device as well as power production and increase the power generation as energy conservation and efficiency. The proposed experimental method could be applicable to the conversion of ocean wave all over the world. In this circumstance the research to find out the renewable energy source of Bangladesh is important to mitigate the increasing power demand and a contribution to reduce global warming.

Acknowledgments

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