Utilization of Oscillating Water Column Technique for Hydro-Kinetic Energy Conversion near sea shore

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Abstract - *The ocean waves are an important renewable energy resource that, if extensively exploited, may contribute significantly to the electrical energy supply of countries with coasts facing the ocean. A wide variety of technologies has been proposed, studied, and in some cases tested at full size in real ocean conditions. One such technique is Oscillating Water Column (OWC). It is integrated with air chamber and can be placed near the shore. Hydro Kinetic force of the waves is converted into mechanical energy and later transformed into electrical energy. This paper reviews various OWC techniques and proposes paddle mechanism linked with air piston to produce air pressure that rotates the turbine. It also analyses the conversion rate of wave force into usable energy form.*

***Key Words*:** **Hydro Kinetic Energy, Oscillating Water Column, Paddle Mechanism, Air Chamber, Sea Shore Energy.**

1. INTRODUCTION

Increasing energy demand, harmful environmental effects of conventional energy production technologies, increasing cost and running out reserves of fossil fuels, climate change, spreading health problems and social pressure have led scientists and engineers to find alternative non-consuming, harmless, cheaper and sustainable energy production methods. Renewable energy technologies offer many environmental benefits over conventional energy sources.

The hydropower is the world's largest and cheapest source of renewable energy. It is also the most efficient way to produce electricity. Approximately 18% of world's electricity is supplied from hydropower. Predictability, regularity and having worldwide spreading sources make hydropower one of the most attractive choices of energy production. There are mainly two approaches to harness energy from water, namely, hydrostatic and hydrokinetic methods. Hydrostatic approach is the conventional way of producing electricity by storing water in reservoirs to create a pressure head and extracting the potential energy of water through suitable turbo-machinery. In hydrokinetic approach, the kinetic energy inside the flowing water is directly converted into electricity by relatively small scale turbines without impoundment and with almost no head.

Hydrokinetic energy conversion systems are the electromechanical devices that convert kinetic energy of tidal currents or ocean waves into electricity without using a special head and impoundment. This new technology became popular especially in the last two decades and needs to be well investigated.

2. LITERATURE REVIEW:

M. Ishak Yuce and Abdullah Muratoglu (2014) had provided detailed review hydro kinetic conversion systems as followed

2.1 Current Energy Conversion Systems (CEC):

Current energy conversion (CEC) systems mainly have a propeller with two or more blades rotating around a horizontal or vertical shaft by the effects of the hydrodynamic forces generated by the free stream. Each blade is basically designed from one or more hydrofoils. The blades rotate with the torque that is produced by the lift force. Selecting a high performance hydrofoil having large lift/drag ratio is important in the design process. [1]

2.2 Wave Energy Conversion Systems (WEC):

Wave energy conversion (WEC) is a hugely varying stochastic process due to diffraction and radiation. Therefore, the theory is mainly device based. Various hydraulic and pneumatic power conversion systems have been developed to convert the dispersed movements of waves into the mechanical power. WEC devices have reciprocating and rotating parts to use hydrodynamic lift force created by the flow over a hydrofoil or lifting structure producing high torque and low speed output. They vary in size, orientation and distance from the shore. These systems can be bottom and shore mounted or floating. [1]

Various WEC Types:

a. **Point Absorber Buoy:**
This device floats on the surface of the water held in place by cables connected to sea bed. The wave energy is absorbed by radiating a wave with destructive interference to the incoming waves. Buoys use the rise and fall of swells to generate electricity in various ways including directly via linear generators or via generators driven by mechanical linear-to-rotary converters or hydraulic pumps.

b. Surface Attenuator:

These devices act similarly to point absorber buoys, with multiple floating segments connected to one another and are oriented perpendicular to incoming waves. A flexing motion is created by swells, and that motion drives hydraulic pumps to generate electricity. Environmental effects are similar to those of point absorber buoys, with an additional concern that organisms could be pinched in the joints.

c. Oscillating Wave Surge Converter:

These devices typically have one end fixed to a structure or the sea-bed while the other end is free to move. Energy is collected from the relative motion of the body compared to the fixed point. Oscillating wave surge converters often come in the form of floats, flaps, or membranes. These capture systems use the rise and fall motion of waves to capture energy. Once the wave energy is captured at a wave source, power must be carried to usage location by transmission power cables. [2]

d. Oscillating Water Column:

Oscillating Water Column devices can be located onshore or in deeper waters offshore. With an air chamber integrated into the device, swells compress air in the chambers forcing air through an air turbine to create electricity.

Antonio F.O. Falcao and Joao C.C. Henriques (2015) had classified OWCs into five types namely (i) Fixed Structure OWC (ii) Breakwater – Integrated OWC (iii) Floating Structure OWC (iv) Multiple OWCs. [3]

2.3 ENERGY CONVERSION SEQUENCE:

Irene Simonetti (2016) in her dissertation work has stated about the energy conversion chain for an OWC device consists in the following steps

a. Transformation of the energy of the incident wave in kinetic energy of the oscillating water column governed by Hydraulic Efficiency.
b. Transformation of the kinetic energy of the oscillating column of water in pressure and kinetic energy of the reciprocating airflow governed by Pneumatic Efficiency.
c. Transformation of the pressure and kinetic energy of the reciprocating airflow into mechanical energy in the air turbine governed by Mechanical Efficiency.
d. Transformation of mechanical energy to electrical energy by means of an electrical generator and complementary electrical equipment governed by Electrical Efficiency.

She had also stated that development of a conceptual model is necessary, predicting the pneumatic efficiency of the OWC device given as input the OWC geometry and the incident wave parameters. The model might be applied *as* a simple designs supporting tool, avoiding the use of more demanding computational tools in the optimization process of OWC devices. [4]

2.4 OWCs WITH TURBINES:

M.J. Khan et. al (2009) discuss about OWCs having horizontal axis and vertical axis turbines which convert oscillating motion of waves to rotary motion of blades and later into reciprocating motion of piston. Hydrokinetic energy conversion may employ either rotary turbo machinery or can use non-turbine schemes. Rotary turbine systems employing horizontal or vertical axis turbines are discussed below.

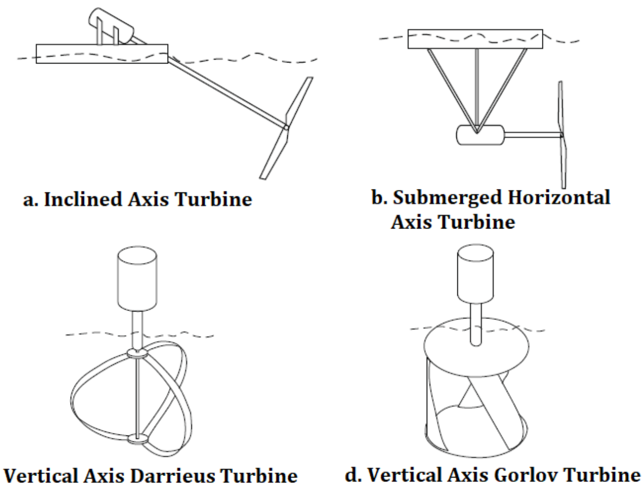

Fig. 1: Turbine Type OWCs

They also insist that presently, most of the other OWC technologies are either at their proof-of-concept stage or being developed as part-scale models. [5]

3. PROPOSED NEW MODEL OF OWC:

OWC with Paddle Mechanism:

Our proposed new model of OWC consists of high raised reinforced concrete structures acting as support frames. Paddle mechanism is planned to be immersed in sea wave centrally supported by journal bearing. Other end of the paddle mechanism is connected to thrust mechanism of the pneumatic cylinder. A helical coil spring is attached to retract the paddle mechanism after compression. Cylinder used for compression is made of higher grade aluminum alloy with an inlet for atmospheric air and outlet fitted with convergent nozzle for compressed air.

Compressed air from nozzle is focused to flow over air turbine which in turn rotates electrical generator for calculated load of electric power.

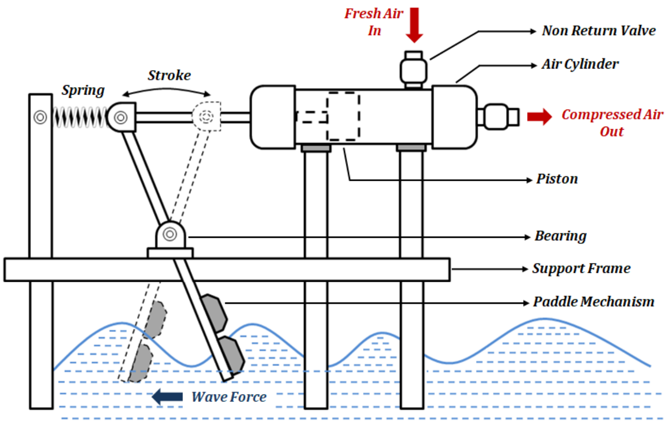

Fig. 2: OWC with Paddle Mechanism

The effective functioning of OWC depends on size of the system, placement of the system, flow characteristics of sea water, stability of the system during storm. Hence an overview of near-shore wave resource and physical attributes of coastal environment should be studied.

Following design parameters are considered for scaled down model and proposed actual model.

Parameters	Scaled Down Tested Model	Proposed Actual Model
Pillar Height	20 cm	14 m
Paddle Length	30 cm	20 m
Float Size	5 cm	3 m
Cylinder Diameter	7.5 cm	1 m
Cylinder Length	30 cm	10 m
Stroke Volume	0.0013 m^3	7.85 m^3
Orifice Diameter	0.5 inch	6 inch
Orifice Coefficient	0.64	0.64
Paddle Oscillation	15 cm	7.5 m
Centre of Gravity from base	15 cm	10.5 m

Table 1: Design Parameters

4. NUMERICAL ANALYSIS:

Power produced by wave passing through the Oscillating Water Column is given by

$$P = \frac{\rho g^2}{64\pi} H_{mo}{}^2 T_e \qquad \dots\dots\dots Eq.1$$

Where, P = Wave Power

ρ = Sea Water Density

g = Acceleration due to gravity

H_{mo} = Significant Wave Height

T_e = Time Period of Wave

Power transferred from wave energy to pneumatic energy is given by

$$E = pV\left[\ln\frac{p}{p_a} + \frac{k}{k+1}\left(\frac{T-T_a}{T} - \ln\frac{T}{T_a}\right)\right] \dots\dots\dots Eq.2$$

Where, p = Cylinder Pressure

p_a = Atmospheric Pressure

T = Cylinder Temperature

T_a = Significant Wave Height

k = Compression Ratio

V = Cylinder Volume

Kinetic Energy available at the end of convergent nozzle is given by

$$E = \tfrac{1}{2} mV^2$$

Where Exit Velocity of nozzle V is given by,

$$V = \sqrt{2000\,(h_1 - h_2)}$$

Mass flow rate m is given by,

$$m = \frac{AV}{v}$$

Where, h_1= Enthalpy of entry

h_2 = Enthalpy of Entry

A = Area of cross section

V = Velocity

v = Specific Volume

Finally, Electrical Energy produced by generator is given by,

$$E = \frac{P\varphi N}{60} \times \frac{Z}{A}$$

Where, P = Number of Poles in the generator

Φ = Flux per Pole

N = Generator speed in RPM

Z = Total number of armature

A = Number of parallel paths in armature windings.

Based on this numerical analysis, considering a normal costal region of minimum wave height of 3m and wave height of 15 m during heavy storms, electrical energy derived is listed below.

Wave Range	Average Wave Height	Wave Time Period	Hydro Power Produced	Electric Power Expected
	m	s	kW/m	kW
Low	3.0	8	36.00	21.60
	4.0	12	96.00	57.60
	5.0	15	187.50	112.50
Medium	7.5	8	225.00	135.00
	9.0	12	486.00	291.60
	10.5	15	826.88	496.13
High	12.0	8	576.00	345.60
	13.0	10	720.00	432.00
	14.0	12	1014.00	608.40
	15.0	15	1470.00	882.00

Table 2: Hydro Kinetic Conversion Rate

5. CONCLUSIONS:

Our study concludes that hydro kinetic conversion systems help to replace the use of fossil fuels. Especially Oscillating Water Column with Paddle Mechanism is an attractive option for reducing dependence on high-cost diesel systems in the many remote areas. OWC is a viable option for generating power in countries that have long coastal lines.

Challenges to developing a commercial hydrokinetic industry include determining the technological, operational, and economic viability of hydrokinetic turbines, meeting permitting requirements, and gaining stakeholder acceptance. Hydrokinetic technology can be affected by debris, sediment, and surface ice, river dynamics (turbulence, current velocity, channel stability), and the effect of turbine operations on fish and marine mammals and their habitat. The question of turbine operation impacts on the aquatic environment is one of the major issues that will determine stakeholder and permitting agency views toward this new technology.

Further work on the OWC can be divided into two general areas. Firstly, further extensive work is required on the hydrodynamics of the OWC to increase performance by improving the coupling of the paddle, water column and waves. This will be achieved using further 2D wave tank experiments, and video analysis together with appropriate numerical modeling. Secondly, 3D wave tank experiments and CFD analysis are required to measure the performance of the OWC in realistic circumstances.

In general, OWC can be excellent renewable energy source converter with expected output power range of 22 kW to 880 kW.

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