Ocean Energy Conversion Concept

Synopsis

A system concept, for wave and offshore wind energy conversion, describes energy conversion devices intended primarily for location in continental shelf waters exposed to un-attenuated waves. Individual features may be mounted on jetty type or other structures in shallower water. Survivability is considered to be paramount. Energy conversion from more than one renewable energy source could reduce overall electricity production cost by using a common under water transmission cable and by increasing electricity production time.
Floating space frames carrying energy conversion devices and large enough to survive severe storms are envisaged. To suppress vertical motion, the space frames could be winched below normal flotation level towards swivelling anchorages assisted by vertical loading from a suspended keel. Bow thrusters at each end could be automatically programmed to control orientation to maximise energy conversion from waves or wind during normal operation or, in severe storms, to direct a protective nose attachment to face into the weather.

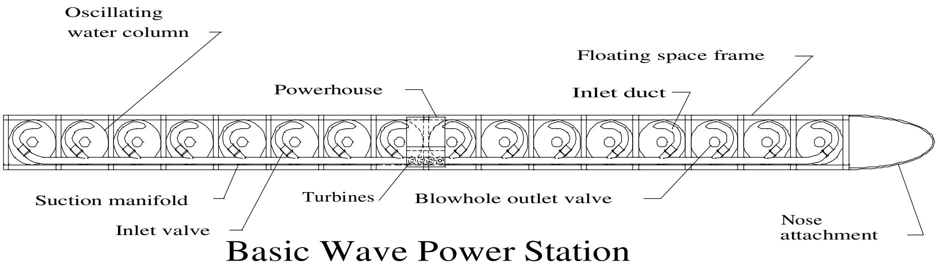
1. Introduction

Offshore renewable energy resources consist mostly of waves and wind. The system envisaged aims for some flexibility to cater for individual site conditions and some early experimentation. Apart from applications on fixed jetty or other structures, the main common feature would be a floating space frame, wide enough to convert available wave energy, deep enough for adequate strength and structural rigidity and sufficiently long to span an ocean wavelength.
A line of oscillating water columns connected by a suction pipe manifold to centrally located air turbines would convert wave energy. Bottom scoops are intended to convert horizontal components of wave motion into increased vertical movement of oscillating water columns. Semi floating side rafts could augment energy conversion by hydraulic lifting rams acting as pumps connected to a hydraulic motor in an onboard powerhouse. They would be tilted up to absorb wave-buffeting forces on oscillating water column sidewalls under severe conditions. Wind turbines either of conventional horizontal axial flow or horizontal or vertical axis cross flow could be mounted over the floating space frames. A suspended keel, submerged outriggers, trim-tanks or a combination could increase stability.

2. Embodiments

Embodiments of the concept are shown in Figures 1 to 11:
Figures 1 is a plan of a wave power station.
Figure 2 is a cross section through an oscillating water column
Figure 3 shows a power assisted blowhole valve.
Figure 4 is a plan view of two oscillating water columns showing connections to the suction manifold and blowholes.
Figure 5 shows inlet valve details
Figure 6 is a cross section through the powerhouse.
Figure 7 is a longitudinal section of a floating wave power station with axial flow wind turbines.
Figure 8 shows horizontal axis cross flow wind turbines and a suspended keel.
Figure 9 shows vertical axis cross flow wind turbines and submerged outriggers.

Figure 10 is a cross section of a horizontal axis cross flow wind turbine and a suspended keel.
Figure 11is a cross section of a vertical axis wind turbine and submerged outriggers.



Basic Wave Power Station
Plan
Figure 1

2.1 Floating space frames

Partly submerged floating open framed vierendeel structures, designed to withstand marine environments, would provide structural integrity, buoyancy and stability and sufficient accommodation space for the energy conversion devices. Fibre reinforced ultra-violet stabilised plastic may prove to be a suitable construction material to form hollow tubular or box sections, threaded with steel cables as a safeguard against catastrophic failure under abnormally violent storm conditions and filled with rigid expanded plastic foam for flotation for upper members with some concrete ballast infill, which could be reduced when suspended keels or outriggers are used, for bottom members.

2.2 Size

Large dimensions are considered desirable for survival in ocean environments. A space frame length of the order of 500 metres is envisaged with a width of around 30m, a height of up to around 40m. Long length together with appropriate orientation control should help to reduce wave power output fluctuation. Space frame height should be adequate for overall structural rigidity and for accommodating underwater energy conversion features while width should be sufficient for to convert design wave power density.

2.3 Suspended keel

For lateral stability against wave or wind caused overturning moments, a keel, consisting of a fibre reinforced plastic shell, could be suspended by lines from floating space frame lower transverse members ends or submerged outriggers followed by sand filling to a required level. If needed, sand could be pumped out at a later date for keel removal.

2.4 Submerged outriggers

An option, for increased lateral stability, could be to attach twin outriggers submerged to just below the water level. Fibre reinforced plastic cylinders are envisaged filled with seawater. If one outrigger is lifted above sea surface level, it should exert a righting force from increased weight of the mass of the water raised above water level. Waves rising over submerged outriggers should exert little more lifting force than drag from water motion apart from short duration wave inertia forces. Alternatively, the outriggers could also act as trim tanks, to counter strong wind loading, by pumping water out of downwind tanks and allowing some air in. Outriggers could also increase floating space frame stability from wide anchorage and suspended keel line lever arms. They could support wire mesh barriers around space frames as protection against trespassers or vandals, with floating gates enclosing the ends. A possible disadvantage could be some loss of intercepted wave energy.

2.5 Anchorages

Anchorages are envisaged in continental shelf waters up to 200 metres deep. A single strong central swivel anchorage point either on the sea floor or above it is needed to allow ship bow thrusters at each space frame end to constantly control orientation to optimise wave and/or wind energy conversion or to face a water ballasted nose attachment towards the weather in severe storms. Winching down against anchorages to the extent needed to hold space frames steady against wave surface movement could improve wave energy conversion. Suspended keel loading could reduce winching down forces required. To reduce hogging and sagging stresses, anchorage lines could be attached from a number of intermediate points along a space frame and automatically winched by onboard winches to achieve pre-determined uniform vertical component forces.

For anchorage, a large diameter appropriately shaped suction type precast caisson[1] is envisaged, lowered on to the sea-bed and drawn down below sea floor level by pumping out underlying continental shelf sediment and water. Research and development may be needed for the suction pumping equipment. Jet pumps mounted on rotating arms may prove successful for a single large anchorage point. Space above could be arranged for infill ballast to weigh down the anchorage. A tremie pipe from a ship could place ballast in position. Should removal be required later, infill ballast could be dredged out, followed by pumping water back into the suction bucket lower section to lift an anchorage up from seabed sediment for recovery. Alternatively a circle of suction caissons, with 45 degree sloping anchor lines, could hold a central swivel point at a height above sea bed equal to the circle radius. Swivelling anchorage is crucial for the concept and should be researched further. Sea floor damage should be minimised.

2.6 Mounting on Other Structures

The energy conversion system components could be mounted on piled jetties or other marine structures, or on a combination of jetties appropriately connected to floating space frames. In some cases, leeward sides of wave-power jetties with appropriate working space could be used for cargo transfer by shipping with reduced wave induced movement of ships.

3. Wave Power

3.1 Wave Power Calculations

An approximate formula[3] for wave power density is: $P = H^2T$ where P is wave power in kilowatts per metre of wave front, H is wave height in metres and T is the time

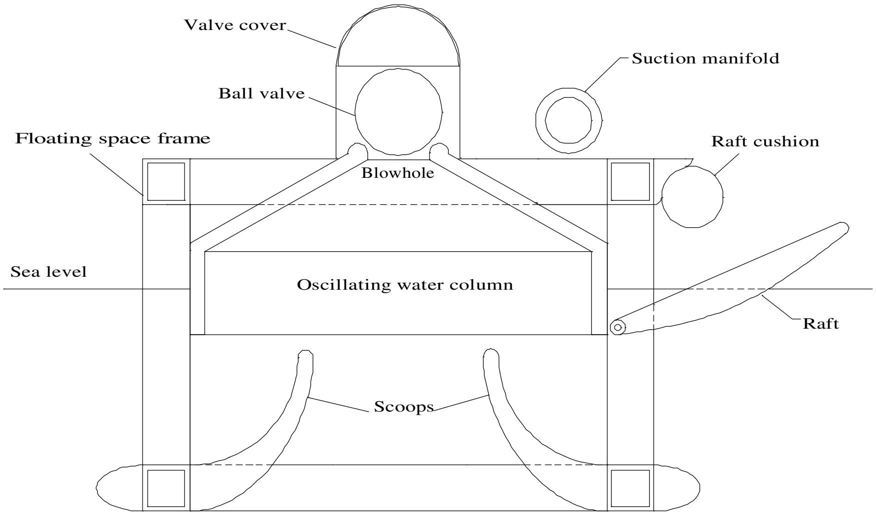
interval in seconds. For example a wave height of 4m at 10-second intervals would have a power density of 160 kW/m.
Assuming that the energy is converted at an average suction head of 2m, the energy captured by a metre of average width from each wave acting over a metre of wave front would be 4x10x2 = 80 kilojoules where 10 is the approximate gravitational force in kilonewtons exerted by one cubic metre of sea water. Over a wave period of 10 seconds it would be equivalent to 8kW per metre of average width.
The average width needed to convert 160kW/m would be 20m. Assuming that oscillating water columns are circular in plan the internal diameter needed would be 20x4/π say 26m. They could be held in a 30m wide floating space frame.
The assumptions made in this calculation need to be tested by appropriate experimental work and reviewed in the light of site wave data.

3.2 Wave form

Theoretically, ocean waves are of trochoidal form with relatively shorter crests and longer troughs[2]. However, investigations[4] have indicated little difference in surface shape between trochoidal and sinusoidal waveforms at commonly occurring ocean length to height ratios. Ocean rollers appear to have noticeably shorter crests followed by longer troughs. It occurred to the author that air drag caused by winds or wave movement could push surface water up from troughs on to crests. Ongoing research into ocean wave shapes may be advisable.

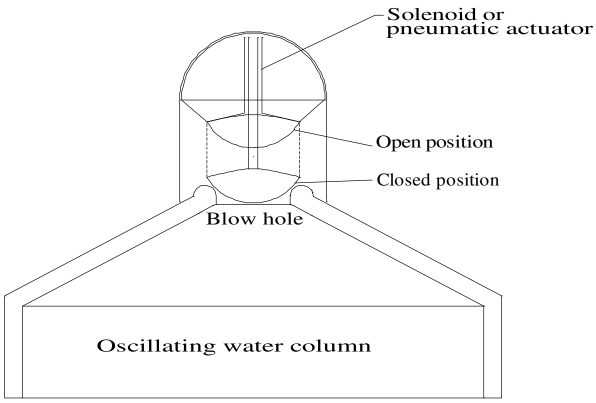
3.3 Energy capture

A difficulty in converting wave energy into mechanical energy is the transient nature of wave motion. Work involves applying a force over a distance over a period of time. Methods of converting the force, while a wave is in motion, can retard water surface motion so that before the process is completed, it is overtaken by the next wave cycle. The author considers that particularly when wave crests are markedly shorter than troughs, maximum power could be converted if potential energy from a water surface raised by a wave is captured before any work is performed. Work would then be performed by air being drawn from a suction manifold through non-return valves into oscillating water columns while water levels fall during trough periods



Wave Power
Oscillating Water Column
Cross Section

Figure 2

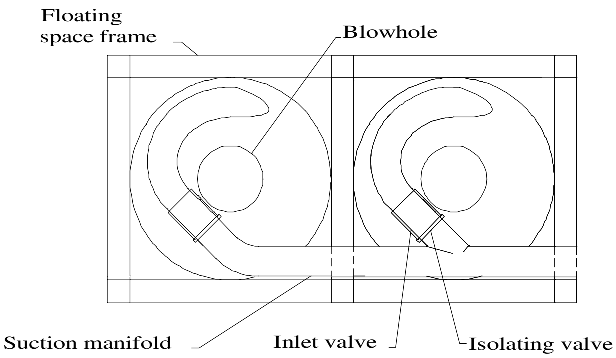


Power Assisted Outlet Valve

Figure 3

3.4 Wave energy conversion

A cross section through an oscillating water column is shown in Figure 2. The inlet is not shown in this view. The outlet is through the blowhole shown via the non-return valve. The valve cover is to prevent seagulls or wind blown flotsam fouling blowhole valves. Figure 3 shows an alternative power assisted non-return valve to improve efficiency. Figure 4 shows in plan the relative positions of inlet valves, isolating valves and blowholes. Air would be drawn from the manifold into oscillating water column chambers through the non-return inlet valves. A section through an inlet valve is shown in Figure 5. The slats may be lifted by air entering the oscillating water column from the suction manifold or they may be power assisted to improve efficiency. An isolating valve placed between an inlet valve and a manifold could be arranged to isolate an oscillating water column automatically should either of its non-return valves fail. Valve and connection details should be researched to optimise design. Air would be sucked out of the suction pipe manifold shown in Figure 1 by the line of oscillating water columns. Sheltered outside air, drawn into the manifold through centrally located air turbines, would generate electricity.



Oscillating Water Column Detail
Plan
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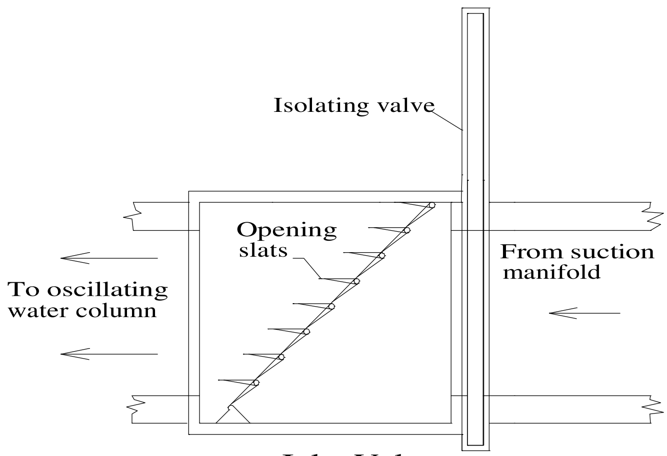
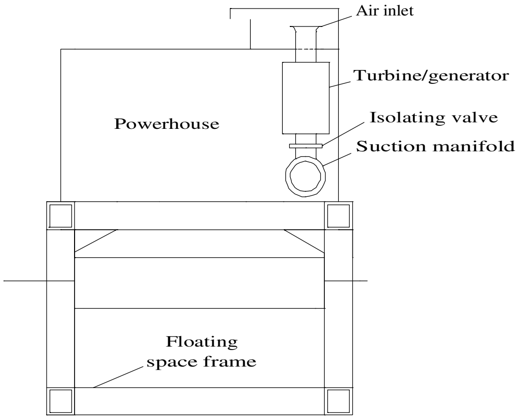
Figure 4



Inlet Valve
Figure 5 ©Peter Ravine 2007

3.4 Water column walls and manifold piping construction

Oscillating water column walls must resist compressive stresses caused by suction, as well as external wave buffeting forces. An appropriate method of construction might be to extrude hollow rectangular or "H" thermo-softening plastic sections, and wind them, appropriately heated, on to rotating cylindrical formwork. A fibre-reinforced plastic skin could be bonded to the outer face. After formwork removal, a fibre-reinforced skin could also be bonded to the inner face. A similar system could be applied to suction manifold piping.
Helical spaces in oscillating water column walls could control buoyancy by flooding to reduce overall buoyancy or by partial emptying at any stage to adjust it.



Powerhouse
Cross Section
Figure 6

3.6 Powerhouse

Figure 6 is a cross section of a central powerhouse containing air turbine generators drawing sheltered air. Separating air turbines from individual oscillating water columns via a manifold should reduce power fluctuation. At any one time, some oscillating water columns would draw air in from the manifold while others would blow air out to the atmosphere. Optimised floating space frame orientation could cause oscillating water columns to reciprocate consecutively rather than simultaneously. Flywheels could further modulate turbines. Isolating valves between the manifold and individual turbines could be programmed to isolate turbines progressively when wave power density falls to increase operating turbine efficiency. Also housed in the powerhouse, but not shown, would be a hydraulic accumulator, reservoir and hydraulic motor/pump powered by hydraulic high-pressure and return manifold lines, not shown, connected to side raft hydraulic rams acting as pumps driving a generator. The hydraulic system would be used in reverse mode when needed to lift rafts.

3.7 Scoops

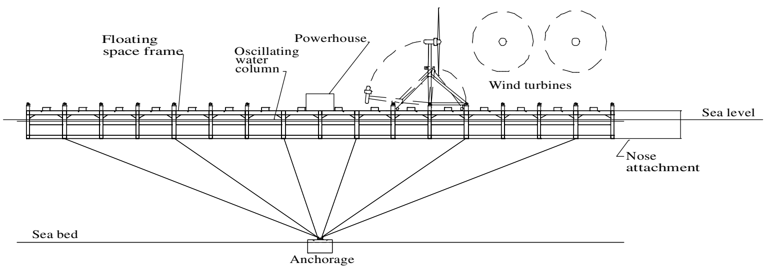
Near-surface water particles under wave action have a circular motion of approximately wave height diameter[2]. Scoops shown in Figure 2 under the oscillating water column are to redirect horizontal components of wave particle movement to increase oscillating water column vertical movement. Research would be needed to optimise their shape and performance.

3.8 Side Rafts

To reduce energy loss from impinging waves, semi-floating rafts shown in Fig 2, are hinged to the floating space frame to guide water down to the scoops under the oscillating water columns. They would also serve three other functions: Firstly to protect oscillating water column walls from wave buffeting in severe storms when they could be tilted up against raft cushions by hydraulic rams, secondly to act as shock absorbers allowing some up and down movement in normal operation to absorb some of the wave force and thirdly to convert the energy so absorbed into electricity by the rams pumping hydraulic fluid to a hydraulic accumulator and motor in the powerhouse.

4. Offshore wind power

Three options are shown for offshore wind energy conversion, namely horizontal axis axial-flow wind turbines mounted on tilt up towers, horizontal axis cross-flow wind turbines with blade lowering facilities and vertical axis cross-flow wind turbines. Possible blade pitch variation for cross flow turbines is discussed. Gyroscopic effects of wind power rotors should help to steady space frames.



Wave Power Station
with Axial Flow Wind Turbines
Longitudinal Section
Figure 7

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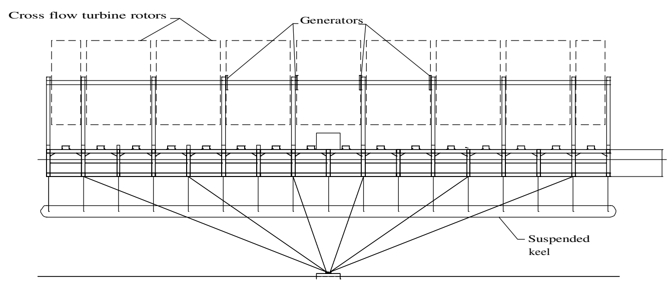
4.1 Axial-flow turbines

Axial flow wind turbines are shown in Figure 7. With this configuration, a 16-cell wave power station might be able to mount six wind turbines. If nose attachments are fitted at each space frame end so that the space over them can be used, the number could possibly be increased to eight wind turbines, with the towers rearranged to tilt outwards. Three legged tilt-up towers are envisaged. Two of the legs could be hinged to floating space frame side nodes on with a third leg acting as a lever arm to raise or lower turbines with winches or other appropriate mechanisms. Lowering turbines to weather severe storms is envisaged.



Wavepower Station
with Horizontal Axis Cross Flow Wind Turbine
and suspended keel
Longitudinal Section
Figure 8

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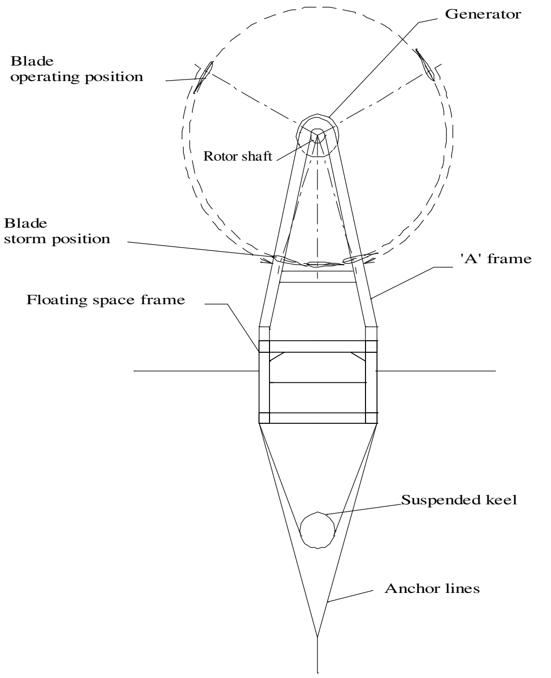


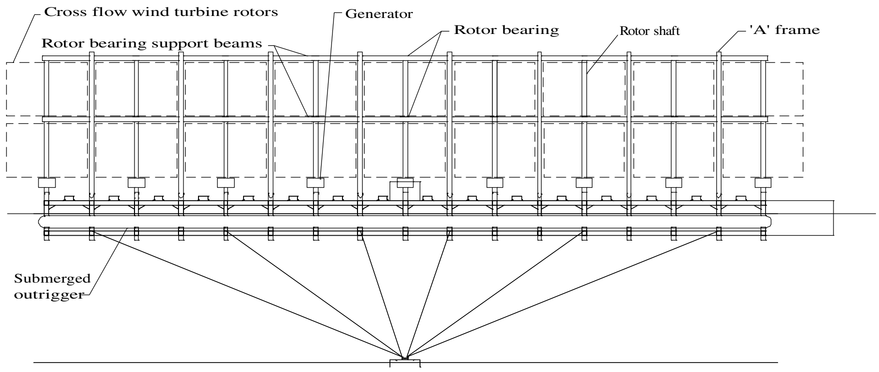
Wave Power Station
with Horizontal Axis
Cross Flow Turbine
and Suspended Keel
Cross Section
Figure 9 © Peter Ravine 2007

4.2 Horizontal axis cross-flow turbines

A horizontal axis cross flow wind turbine option is shown in Figures 8 and 9 aimed at increasing intercepted wind area. Rotor blades could be helical to reduce pulsing. Alternatively, for a three-blade configuration, with rotor shafts coupled together, straight blades could have a similar effect to helical blades if each section is stepped 15^{o} from adjoining sections. Straight blades could assist in developing variable pitch cross flow rotors. Coupling shafts together could reduce the number of generators and permit isolating some generators by appropriate release mechanisms to increase torque on remaining generators to raise light wind generating efficiency. Flat, direct drive, large diameter generators could be secured to supporting “A” frames.

Blade lowering is envisaged to survive storms. Remotely controlled bolts or shear connectors could release blades to enable them to rotate freely on a drive shaft and be re-fixed at predetermined positions when bolts are re-engaged. A generator, used in motor mode, could place a blade to be lowered at its lowest point. The connectors for that blade would be released and the rotor shaft could be rotated until the released blade rests against an adjacent blade. The blade could then be locked in its new position. The process could be repeated for the third blade and for remaining rotors. Automatic computer controlled blade lowering is envisaged.

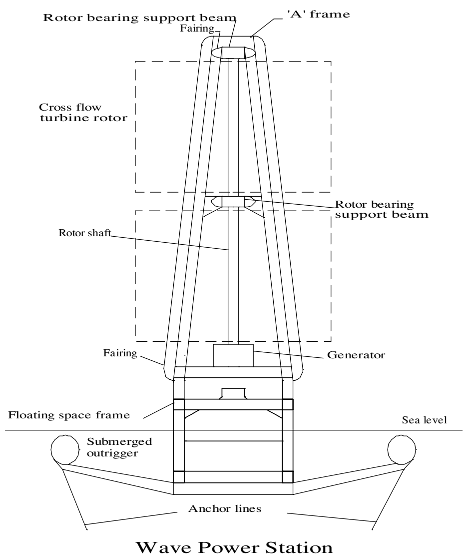
Blade lowering could lower both the rotor centre of gravity and the centre of air drag during severe storms. Blade-lowering features could also be expected to facilitate rotor erection and dismantling by reducing lifting height.



Wave Power Station
with Vertical Axis Cross Flow Wind Turbines
and Submerged Outriggers
Figure 10

4.3 Vertical axis cross-flow turbines

A third option for offshore wind power conversion is shown in Figures 10 and 11 with vertical axis cross flow wind turbines. Generators located low down could lower their centre of gravity and facilitate erection and maintenance. If needed, cross wind overturning moments could be countered by transferring water from balance or trim tanks in submerged outriggers. Their power output may be less sensitive to floating space frame orientation. During storms, with protective nose attachments facing into the weather, vertical axis cross flow turbines might be able to keep running, because, being in line, one behind the other, wind velocity differences across individual turbines may possibly be small enough for power generation to continue safely in high winds. Ongoing research should include the subject.



Wave Power Station
with Cross Flow Vertical Axis Wind Turbine
and Submerged Outriggers
Cross Section
Figure 11

4.4 Cross flow turbine pitch control

While cross flow turbines could increase intercepted wind area on a floating space frame of given size, the advantage could be offset by lower fixed blade darrius rotor efficiency compared with axial flow wind turbines. Efficiency could possibly be improved by mechanically varying blade pitch, in the manner of Voith-Schneider[5] propeller blades. Alternatively, electronic drive motors responding to rotor position and onboard computer generated radio signals could possibly control blade pitch without requiring mechanical linkage and, in addition, feather blades if needed to reduce storm drag. Research and development would be needed.

5. Symbiotic Fish Development

Worldwide reports of overfishing reducing fish populations have become frequent in recent years. Sunken wrecks are known to provide favoured sheltered fish habitats. Suspending appropriately mesh sized underwater netting under ocean energy conversion space frames, could possibly partly protect hatchlings and smaller fish species from over fishing and predators.

6. Conclusion

The concept is seen as a way to make significant progress with renewable energy deployment, offering new opportunities for offshore engineering, oceanography, naval architecture, shipbuilding, construction, wind-turbine, and hydraulic, electrical and other industries. Governments, financial institutions, utilities and industries could sponsor research and development projects. Universities, consultants and research organizations might be interested in undertaking projects aimed at evaluating and optimising concept features.

7. References

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2. Hennes R. G. and Eske M. I. *Fundamentals of Transportation Engineering*. McGraw-Hill 1955. Chapter 36. *Wave Motion*.
3. Duckers L. *Wave Energy*. Chapter 8, *Renewable Energy*. Oxford Press and Open University 1996.
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5. Web site: http://www.voith-hydro.de/english/

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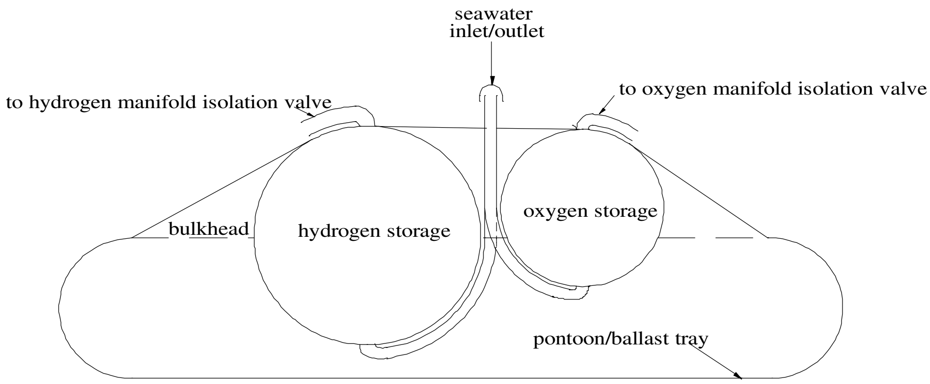
Draft Addendum

Linear Underwater Gas Storage

Prefabricated Float Out Units.

To minimize underwater work and to make storage units more robust, an option could be to prefabricate storage units onshore in the form shown below and then to float them out and sink them in deployment positions. Little, if any, prior seabed preparation may be needed.



Linear Underwater Gas Storage Float Out Unit

Once in position, sufficient seabed sediment could be pumped into pontoon/ballast trays to prevent units from floating when tanks are filled with gas. It may be possible to construct units out of high-density polyethylene (HDPE) or polyvinyl chloride (PVC), stabilized to withstand underwater environments.

Tanks would be cylindrical with hemispherical ends. Internal flexible bladders may be advisable to prevent contamination and/or losses to or from seawater. The tank shapes would allow bladders to be pushed in evenly by seawater, without kinking, as gas is removed. Final crease lines may require special treatment.

Units would be connected to underwater gas manifold piping with appropriate, such as push-on, joints. Isolation valves would then be opened to fill them with gas. Each gas should have its own separate joint diameter to prevent inadvertent cross connection.

Electricity Generation

An option for generating electricity may be to use oxy-hydrogen and oxy-ammonia turbines along lines outlined by Charles W Foresberg of the US Oakridge National Laboratory in paragraph 6.1.1, headed “ Steam Turbines Without Boilers” of his paper on peak electricity:
http://www.ornl.gov/~webworks/cppr/y2001/pres/125179.pdf