Offshore Wave and Wind Together - Afloat

Neal A. Brown, PhD

Float, Incorporated
4903 Morena Blvd, Suite 1213, San Diego, CA, USA, nbrown@floatinc.com

ABSTRACT

Offshore wind and wave power are, or can be, remarkably complimentary. Given a very large, stable and durable floating platform to share, important economies of renewable power production, energy storage, access and maintenance are possible. Fig. 1, below, shows how wind and wave resources share the power potential.

Keywords: renewable energy, ocean wind energy, ocean wave energy, energy storage, offshore ocean energy

1. INTRODUCTION

The offshore, floating wind and wave energy system is made up of closely related functional parts. See Fig. 2. Central is the floating, stable support platform that places both energy-collecting units where the targeted energy is, largely un-attenuated and relatively steady: offshore in deep water. The platform serves as a base, not only for the energy collectors, but for their necessary maintenance, in conditions close to those ashore, as well as for a sizable potential energy store to assist load leveling. Further, the platform supports the electrical (or other) power conditioning equipment and cabling for the entire wind & wave "farm," in largely land-like, accessible, in-the-dry conditions.

2 THE RESOURCE

As derived from Reference [1], incident wave power (kW/m) can be directly related to the generating wind speed in knots (V) in the Pierson-Moskowitz (P-M) and in the more energetic North Sea JONSWAP spectra, respectively by:

$$\text{kW/m} = 5.05 \times 10^{-6}\, V^5\,,\ \ 8.39 \times 10^{-6}\, V^5 \qquad (1)$$

Notable is the 5th power dependence on wind speed for the incident wave power, in contrast to the 3rd power relationship for the wind turbine-accessible wind power, itself – as reflected in Fig. 1. The incident wave power may be present for a longer duration than that of the wind. Further, depending on location, waves may arrive from remote areas with little attenuation; originally driven by "other people's wind"!

3 THE PLATFORM [2]

Concepts exist for very large floating platforms, moored offshore, with superior motion stability and load capacity in challenging sea-state environments. The generic type is termed a Pneumatically Stabilized Platform (PSP). It achieves its at-sea motion stability and structural loads mitigation by decoupling the "hull" from ocean wave pressures through the use of air buoyancy, which is both compressible and mobile. The air is contained in an array of interconnected, open-bottomed, cylindrical tanks. The air is made mobile by means of ducting, the arrangement of which is selectable in real time to best suit the sea-state environment and platform deck loading. Local air pressure adjustments are made via Roots-type blowers, as needed.

The PSP is constructed, modularly, in pre-stressed, reinforced concrete, which, if properly formulated and applied, has been shown to be degradation-free in long term exposure to sea water. In contrast to steel hulls, a concrete PSP need never be dry-docked for inspection, and requires no significant maintenance of the basic hull. Its useful life is expected to exceed 50 years. See plan section, Figure 3.

Unlike sea bottom-mounted wind turbines, a wind farm deployed from such a floating platform can be positioned far offshore in deep water and without regard to sea bottom characteristics. Offshore is also the preferred location for the wave energy converters (WEC) so that no reduction of incident power density by bottom losses need be suffered.

Most significant from a practical (that is economic) point-of-view, is that only concrete touches sea water in the platform, WEC or wind turbine systems. All equipment subject to maintenance, replacement or inspection is "in-the-dry" – fully accessible to personnel on foot, dry-shod. Maintenance personnel can comfortably live on the platform.

The platform is moored in deep water by means of steel chain or cable in catenary configuration, or taut-moored using synthetic lines. Anchors may be of the removable suction-pile, or the plow-types. Mooring technology is well developed in the offshore industries.

4 THE WAVE ENERGY CONVERTER [3]

The "Rho-Cee" (ρC) Wave Energy Converter (WEC) system is subtitled "The Impedance-Matched Terminator". It is a large, floating Oscillating Water Column (OWC) system, integrated with the Float PSP to take advantage of the controllable stability, load capacity and deck area that it provides when moored in deep water. The name "Rho-Cee" derives from the expression for the characteristic impedance of water gravity waves; the product of water mass density, ρ, with the length-dependent velocity of such waves, C. It is the base principle of our WEC design that its input impedance matches the characteristic impedance of the targeted waves. Impedance matching maximizes the capture of wave energy; with minimum reflection.

Several constraints dictate that the input impedances of the absorber elements be quite small. This requires resonant operation of the OWCs. Hence, several water columns are tuned to frequencies, with band-widths that span the energetic region of the yearly average incident wave power spectrum. The normalized bandwidths govern both the resistive input impedance and the output power potential of each oscillator.

The successively-tuned water columns are geometrically "nested" to minimize space and weight of materials – hence cost, as may be seen in Fig. 4. The nested units are then repeated, endwise, to form a linear array of identical contiguous WECs in a two-dimensional "terminator" configuration – one that is aligned perpendicular to the usual propagation direction of incident waves.

The currently favored means to transduce OWC motion to output electric power is diagrammed in Fig. 5. It is quite possible to maintain linearity in the pressure-velocity relationship, hence constancy of OWC input impedance, via hydraulic motor displacement control on a near-instantaneous basis. The impedance is also readily adjusted to account for variations in the waves' incident direction relative to the normal direction. Other means of transduction in the power take off (PTO) include linear oscillating generators or air turbine-generators. While other means might be simpler, or more efficient, they can not now be procured as "commercial-off-the-shelf" (COTS) products.

5 ENERGY STORAGE [4]

Finally, both Wind & WEC are uniquely capable of storing substantial amounts of potential energy in their common supporting PSP structure. That potential energy is embodied in compressed air residing in closed volumes and buoyancy cylinders of the PSP; charged and tapped by reversible motor-driven Roots blowers that are already part of the platform system. That energy can be tapped during intervals of low wave or wind activity to better match varying demands of the load infrastructure, thereby avoiding the principle objection to renewable energy sources.

With compression to three atmospheres (gauge), by Roots blowers connected in series, a PSP platform of typical height may store the pressure x volume equivalent of 10 MW-hrs of potential energy per hectare (4 MW-hrs per acre) of deck area. As the compressed air will have cooled to ambient temperature, it will be advisable to add heat before expansion in order to increase and maximize energy output; avoiding sub-cooling of the exhaust air. The heating may come about by combustion of a fuel, preferably Hydrogen self-made by electrolysis with the excess power.

6 A FIRST WAVE & WIND CONCEPT

A floating breakwater of 2.5 kilometers length, fitted with both "Rho-Cee" WEC's and wind turbines, was intended for the port of Leixoes, in the north of Portugal. The breakwater was conceived as a means to enlarge the port's docking capacity for Atlantic shipping; in as it was limited by the configuration of the very old port with its stone breakwater. The new arrangement was also intended to lend shelter to the more southerly mouth of the River Douro. With an annual average incident wave power of approximately 56 kW/m, it was expected to deliver 70 MW power to the local grid, with a somewhat lesser amount from the wind turbines. Estimated costs for delivered wave energy were in the vicinity of US$0.09 per kW-hr, assuming 50% of combined platform costs and capital at 4% for 20 years.

Not being offshore, the project was hampered by the expression of "NIMBY" by residents of the shore to the south, and was moved further north to the smaller port of Viana do Castelo, where it was more acceptable. However, all came to an end with the financial crisis that particularly effected Portugal.

7 A MORE COMPREHENSIVE CONCEPT

In order to enlarge the wind turbine capacity proportion of the wind & wave offshore farm, the generic arrangement of Fig. 6 has been suggested. Here, the WEC-bearing PSP is again intended to fill the "aperture" of the farm, but an attached wind turbine-bearing structure is extended and protected to leeward. In contrast to the PSP portions, which are here narrower than before, the wind turbine-only support is proposed to be constructed as a buoyant, truss-like structure made of reinforced, pre-stressed concrete culvert pipe. This is attractive because concrete culvert is a mass produced product with well known properties [5]. It is also relatively inexpensive!

A construction concept for such struts, here in 15 foot ID, 13.25 inch (load bearing) wall culvert pipe has vertical bulkheads interspersed, which bulkhead structures reach to well above the waterline. The culvert pipe struts are assumed to remain submerged at a depth (TBD) that allows for efficient structural connection to the PSP. Note that the air-filled culvert pipe has a net buoyancy of about eight tonnes/m. The bulkheads, with freeboard, may serve as stanchions for supporting tracks and walkways for access of personnel and heavy equipment (cranes, trucks) to all parts of the farm. The bulkheads are to serve as anchor structures for the numerous pre-tensioning tendons that hold the concrete culvert pipe sections in axial compression. Any one such strut-member should provide sufficient bending strength to avoid tensile stresses under the extreme moment loading of a single wind turbine – whereas there are typically three struts sharing the load to some extent.

The spacing of wind turbines in Fig.6 is 200 m, with rotor diameters of 90m assumed; the swing-circles of the rotors may be noted.. The "span" of the farm is therefore 1040 meters. There must be a trade-off performed to adequately evaluate the output product vs. the "costs" in performance, capital and maintenance associated with both lateral and leeward spacing of the wind turbines, i.e. aerodynamic interferences. Note that each wind turbine located at the intersection of three struts is fitted with a "lily-pad" of decked PSP foundation structure that provides access for maintenance, as well as strength and buoyancy. A PSP section is fitted to one of the leeward legs to serve as a sheltered docking facility. A helicopter pad will also be fitted where air operations will not be threatened by the wind turbines

While the costs and productivity of the new wind & wave platform concept have yet to be detailed, very preliminary estimates of platform "hull" capital costs are falling in the range of $1,400 to $1,800 per total (wave plus wind) rated kilowatt, for energetic areas. We believe this is influenced by the prospective use of the relatively inexpensive concrete culvert strut structures to spread wind turbines vs. using the PSP which is priced mostly by area. On the other hand, it is a matter of on-going investigation to determine how the rating of a WEC should be established relative to the statistics of its production.

References

[1] W.H. Michel, "Sea Spectra Revisited," *Marine Technology*, Vol. 36, No. 4, Winter 1999, pp. 211-227

[2] D.A. Innis, "Stabilized Floating Platform Assembly," US Patent No. 5,375,550, Dec. 27,1994

[3] N.A. Brown, "The Rho-Cee wave Energy Converter – Impedance-Matched Terminator," *Energy from the Oceans*, SNAME Texas Section, February 9, 2010, Houston, TX.

[4] N.A. Brown and D.A. Innis, "Offshore Floating Ocean Energy System," *USPTO Application No. 12/728,191*, 03/19/2010.

[5] Anon, "Ameron Prestressed Concrete Cylinder Pipe," PCCP 10/02, Ameron Corporation, 2002, www.ameronpipe.com.

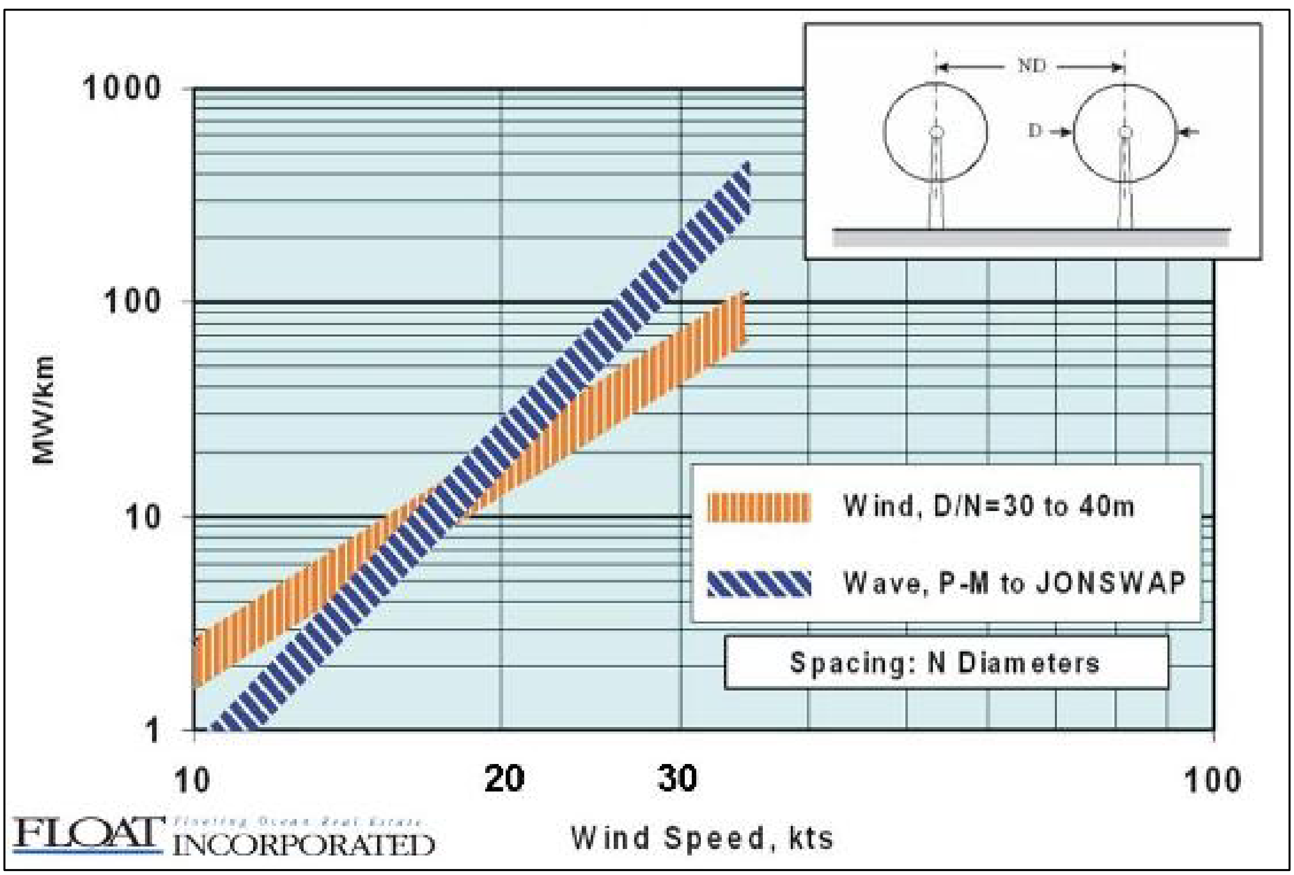

Figure 1 Available power comparison, wind and wave (Pierson-Moskowitz, JONSWAP spectra)

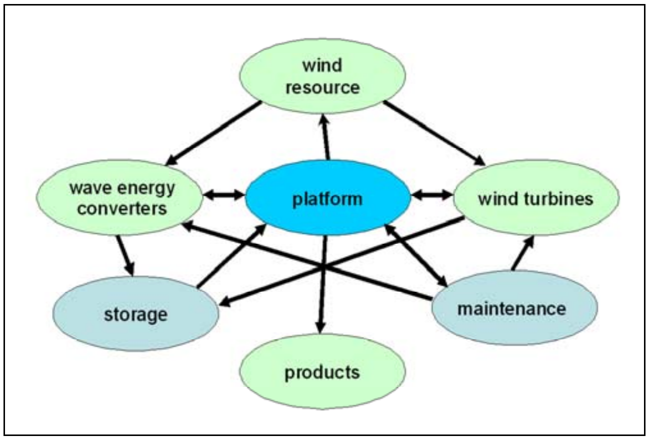

Figure 2 Offshore floating W & W system connections

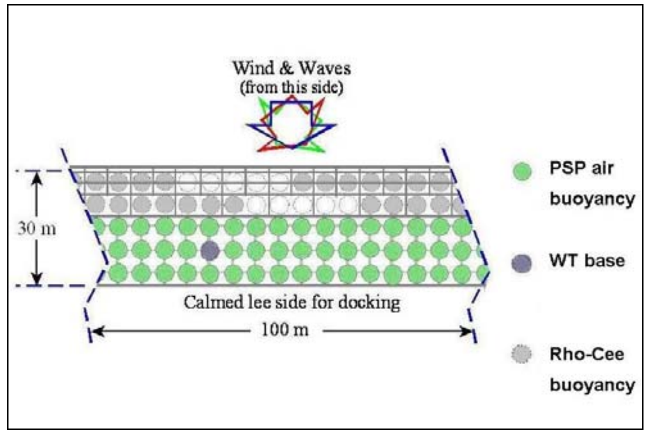

Figure 3 Plan section of PSP with Rho-Cee & WTs

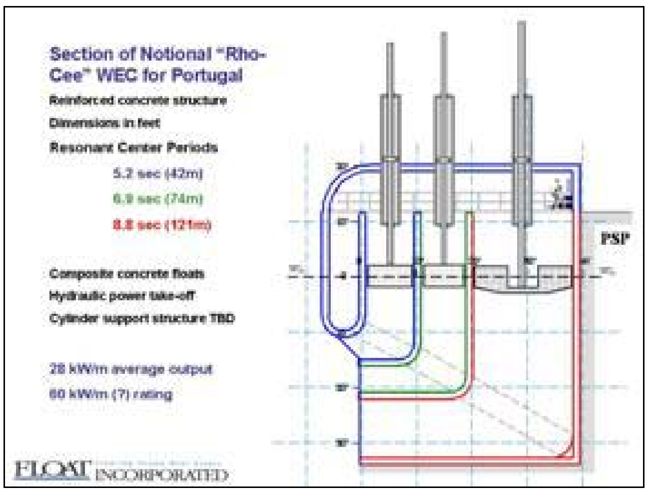

Figure 4 Section of Rho-Cee WEC for Portugal

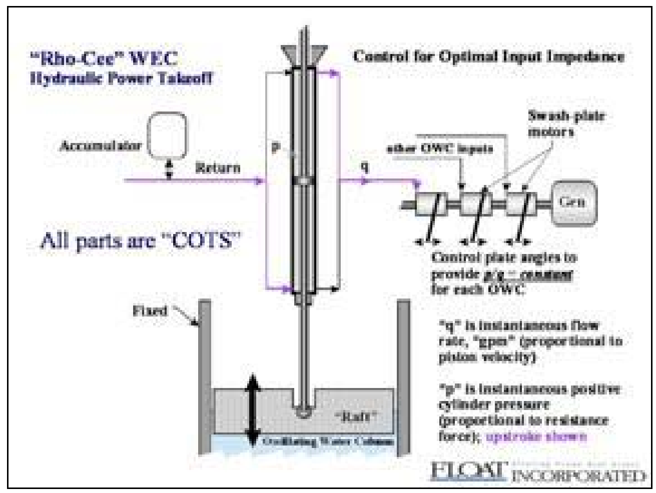

Figure 5 Rho-Cee WEC hydraulic power takeoff (PTO)

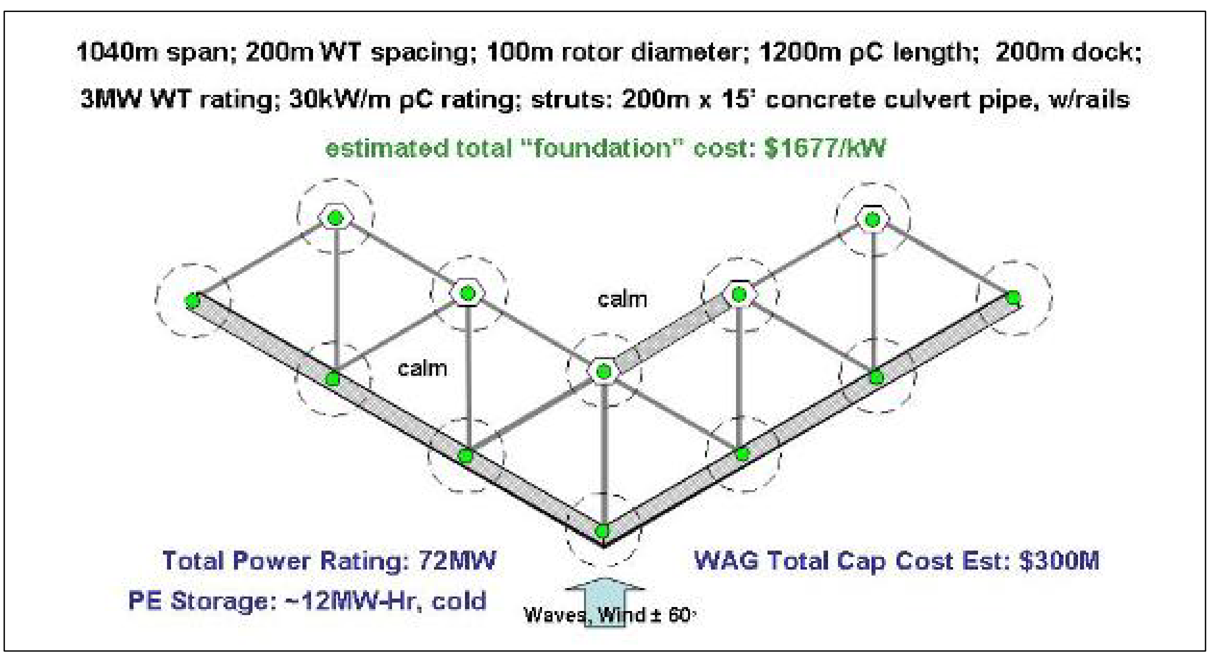

Figure 6 Plan of Platform: Combined Wind & Wave - Afloat

Clean Technology 2011, www.ct-si.org, ISBN 978-1-4398-8189-7