Large Scale Manufacturing and Deployment of Offshore Renewable Energy Harvesting and Storage Systems

Alexander Slocum[1], Gökhan Dündar[1], Brian Hodder[1], James Meredith[1], Elie H. Homsi[2], Andreas Garg[3], Christoph Lay[3], Horst Schmidt-Böcking[4], Gerhard Luther[4]
[1]*Massachusetts Institute of Technology, USA*
[2]*Flatiron Corp, USA*
[3]*HOCHTIEF Solutions AG, Germany*
[4]*Universitaet Frankfurt and Saarbruecken, Germany*
slocum@mit.edu

Abstract

This paper describes a system for utility-scale offshore energy harvesting and storage where hollow concrete spheres are located on the seafloor and act as moorings for a tension leg platform (or moored structure) to which ocean energy harvesting devices can be attached such as wind turbines and wave energy harvesters. A sphere with an inside diameter of 25 m and a wall thickness of 2.6 m operating at 70% efficiency in 320 m of water can store 5 MWh of energy and would have a mass of 21,000 tonnes and be self-ballasting. To store energy, water is pumped out of the sphere leaving sub-atmosphere pressure inside. To generate power, water flows through a turbine back into the sphere. Tension leg(s) for securing the floating platform would serve as power conduits, guide rails for maintenance ROVs, and could also serve as vent lines. To yield a 4 GW offshore wind farm with integral storage would require the manufacture of about one concrete sphere a day for 5 years, where each sphere would anchor a floating platform that could support a 5MW wind turbine. Levelized cost of energy from the system would range from \$0.12 - \$0.20 /kWh. The cost is greatly affected by production and deployment technology, and this paper will describe methods for large scale manufacturing and deployment of these large spheres, as well as the floating energy harvesting platform.

1 Concepts

Pumped Storage Hydroelectric (PSH) is the oldest and most common form of utility-scale energy storage [1]. During low demand, energy is used to pump water from a lower reservoir to a higher reservoir. During a period of high demand, the water in the higher reservoir flows back down to the lower reservoir through the same pump (typically a Francis pump, now acting as a turbine) to generate electricity. The power capacity of the system is proportional to the head (height difference between the upper reservoir and the turbine) and flow rate. The energy capacity is further proportional to the volume of reservoirs available for the turbine. Round-trip efficiencies of PSH range from 70% to 85% [2]. As early as 1971, it was proposed to place hollow structures on the seafloor to act as PSH systems. When water is pumped out of the structure against the outside pressure of the seawater, energy is stored, and then is recovered by letting seawater flow through a turbine attached to the structure on the seafloor [3]. The structures, however, are massive, and thus here we also propose that they be used as moorings for Floating Wind Turbines. Manufacturing, and design for manufacture, is the key to success.

Table 1: Spherical Camber/Conical Base Parameters

Density sea water (kg/m^3)	1025	
Density concrete (kg/m^3)	2400	
Inner diameter (m)	25	
Concrete strength (MPa, psi)	34.5	5000
Strength Factor of Safety	1.5	
Minimum ballast safety factor	1	
Inner volume (m^3)	8181	
Required ballast for inner volume (mt)	8386	
FWT anchore system	Moored	TLP
Required ballast for anchoring FWT (mt)	500	3000
Total required submerged ballast (bouyancy accounted for) (mt)	8886	11386
Volume of concrete required for ballast (m^3)	6462	8281
Sphere wall thickness required to be self-ballasting (m)	2.7	3.6
Actual total submerged ballast (mt)	11845	15776
Actual dry land weight (mt)	20675	27536
Actual ballast safety factor	1.4	1.9
Maximum safe working depth made possible by wall thickness (m)	996	1337
Pump/turbine efficiency	70%	70%
Planned deployment depth (m)	400	400
Charge capacity at planned deployment depth (MWh electric)	6.4	6.4
Maximum charge capacity at max possible depth (MWh electric)	15.9	21.4

Even in deep water, conventional PSH turbines can operate with up to 750m of head, a sphere with an inside diameter on the order of 25-30 meters will be required to store several hours of energy at the peak power rating of a large (5 MW) offshore wind turbine. See Table 1. The challenge is how to make such a large sphere given that it will be negatively buoyant and the deepest channels from ship construction sites are typically only 15 meters. Casting and curing times will be on the order of weeks, so to build a large-scale wind farm will require many units to be made in parallel. Note a 3m thick wall requires the pour to be cooled during curing.

1.1 Monolithic Sphere

A monolithic sphere can be cast in a number of ways, from shotcreting an inflated balloon, to filling a mold where a steel core is made from wedges that can later be extracted through a hole in the pole of the sphere. Slip casting methods can also be used. If a monolithic sphere is cast on shore, then it will have to be moved onto a large special purpose barge or submersible platform. With a draft of say 12m and a beam of 30m, the barge would have to be about 80m long. Once on site, it could be slowly submerged, the air-filled sphere held by cranes, which only need to support the unballasted weight of about 3000 tonnes.

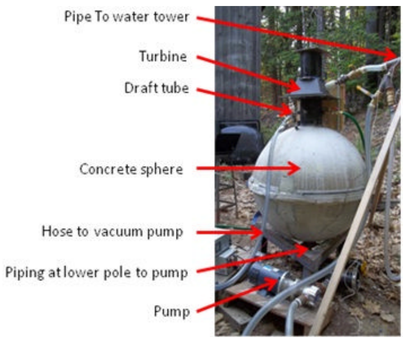

Figure 1: Land-based test system using cast hemispheres

1.2 Hemispheres

Two hemispheres can be made independently and then bonded together. Figure 1 shows a 0.75m diameter sphere we tested on land at the base of a 12m tall water tower. The two halves were epoxied together. The hemispheres could be cast vertically and then brought together for bonding, or they could be cast one up and one down, and then floated out using barges. One barge submerges to where the up-facing hemisphere is below water enough for the second down facing hemisphere to be floated over it and then engaged. Choreographing the event and getting a good bond would likely be problematic.

1.3 Rings

Motivated by the segmental concrete bridge industry, a sphere could be assembled from match-cast segments. Here the top surface (new cast bulkhead) of the first section is coated with a mold release and used as match cast bulkhead for the next section. The bulkhead form will incorporate shear keys that would be match cast. These keys will help align the segments and provide added shear capacity. The rings can be easily reinforced by circumferential rebar cages and/or longitudinal and latitudinal post tensioning tendons. After curing, the rings would be stacked on barges and then assembled on site on the deck of a submersible barge or platform that submerges a little each time a ring is added. As a ring is added, the weight increases, but so does the buoyancy; hence the load on the barge only increases slightly up to the maximum ballast of the sphere (3000 mt for a sphere to anchor a tension leg platform, or 500 mt for each of three points for a moored structure). From a precision engineering perspective, alignment of the rings is ensured by match casting and by the shear keys; however, differential thermal expansion caused by temperature gradients will have to be controlled by monitoring temperature of the elements and spraying water as needed.

References:

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