Comparison of underwater with conventional pumped hydro-energy storage systems

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***Abstract*. The laws of fluid mechanics imply that modular off-shore hydro-energy storage systems have no advantage over similar but much cheaper on-shore storage systems.**

The storage of electrical energy is a still unsolved problem. The potential of pumped-hydroelectricity storage in reservoirs at high altitude has been mainly exhausted. Typical round-trip efficiencies of alternative systems (like electricity-gas-electricity) are low, and to fully store and retrieve the energy delivered by a single wind turbine, three additional wind turbines are required in the average. In this context, underwater pumped hydro-energy storage offshore is frequently described as an emerging technology with significant potential, see [1], [2], and references therein.

The Stored Energy at Sea (StEnSEA) project of Fraunhofer Society and Hochtief AG, for instance, proposes to use hydro-energy storage in large farms of hollow concrete spheres, installed at water depths of about 800 m, each sphere of diameter 30 m, wall thickness 3 m, and mass 10 000 tons [3]. To store surplus electrical energy, the water-filled spheres are evacuated by pumping the water out against the immense pressure of deep water surrounding the spheres. To recover the energy, the spheres are refilled with the water streaming onto the pumps, which then act as generators. Energy flows back and forth to a sphere through an underwater cable. No land area is required for this type of hydro-energy storage.

At first sight, this idea of a modular underwater energy storage system is quite seducing. Unfortunately, it turns out that such a system has no advantage over a more conventional approach that uses reservoirs of similar volume, but installed not underwater but onshore on an elevated coast. This follows from the law of Torricelli, which states that the speed of a fluid, streaming out of an opening in the bottom of a tank filled to a height H, is the same as the speed the same fluid would acquire in falling freely from an equal height H. Hence, if the StEnSea spheres are filled and emptied deep underwater at depth H, their energy storage capacity is not larger than if they are installed onshore at a steep coast at elevation H and emptied via a downpipe onto a turbine at sea level, because their storage capacity depends solely on the speed of water falling onto the turbine.

In an onshore scenario, the water reservoirs need not be thick-walled concrete spheres, but can have any shape, open or closed, and can be thin-walled like a paddling pool. To their low fabrication cost one can add the ease of installation and maintenance, and the absence of a harsh maritime environment. Furthermore, for the underwater system viable locations in the world are rare, see Fig. 2 of Ref. [4], because the system should be installed on a horizontal sea ground with depths limited to 600 to 800 m, and should be close both to offshore wind farms in shallow waters and to the onshore electrical grid. In contrast, locations for modular systems installed onshore at a steep coast abound, as a look onto the world's coast lines on topographic maps reveals. There are no competing land uses of a steep coast line, and the environmental impact is very low.

In conclusion, should a modular pumped hydro-energy storage system based on a large number of small reservoirs be considered useful (I leave this question open), then an onshore modular system serves the same purpose as an underwater offshore system, but requires an immensely smaller effort. Unfortunately, the interested public seems not to be aware of this state of affairs, and tends to misinterpret often repeated statements of the type "the system takes advantage of high hydrostatic pressure of deep water" [2], thinking that high pressure is a decisive asset of the underwater method, while it is an unnecessary burden.

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