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Buoyant Energy—balancing wind power and other renewables in Europe's oceans

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ABSTRACT

Buoyant Energy is a new approach to store electrical energy offshore and decentralized, based on the well-established technologies of pumped-storage hydropower. This paper focuses on the basic concept and deals with some key features this new storage solution provides. Subsequently to the explanation of the main functionality of the storage concept other important parameters like the efficiency (more than 80% are estimated), the storage capacity (approximately 1 MWh for a solution with the dimensions of $50 \times 50 \times 38$ m) and the high adaptability that provides numerous possible locations are discussed. This is followed by a basic cost assessment which demonstrates the economic feasibility for three different scenarios. The results indicate, that the break-even point is reached between 5 and 30 years but in each case within the proposed lifetime of 50 years and more. The final case study evaluates the effects of integrating deep offshore wind power balanced by integrated Buoyant Energy units. The rising flexibility of the overall system and the direct conversion of the intermittent to a constant power source over a pre-determined period are some benefits as shown in the results.

1. Introduction

Reliable access to cost-effective electricity is the backbone of a modern economy. Without significant investments in electrical energy storage, the envisioned transformational changes towards a sustainable electric grid infrastructure are at risk. The lack of efficient and cost-effective energy storage technologies is a serious barrier to keep pace with the increasing demands for electricity, arising from continued growth in productivity and the increase in distributed renewable energy sources. Marine renewable energy is one particular field that is expected to contribute significantly to the energy mix of the future. Several storage systems are under development and compete with each other. Promising examples are the Tension Leg Platform integrated Hydraulic Accumulator [1], the StEnSea subsea energy storage technology [2], Ocean Renewable Energy Storage [3], Energy Bags for underwater Compressed Air Energy Storage (CAES) [4] and Constant Pressure Accumulators for Offshore Wind Turbines [5]. However, an energy storage solution that can be directly integrated in such volatile energy sources like floating offshore wind turbines would lead to benefits like the higher flexibility of the overall system (wind turbine and energy storage), the exploitation of wind energy at deep offshore sites, cost reduction due to multi-use, etc.

The mentioned lack of available storage solutions affects offshore project development plans in many European regions. Thus, there is a transnational need for action in this respect.

2. Vision

Buoyant Energy (BE) is an offshore energy storage solution based on pumped-storage hydropower (PSH) technology. Today storage of electrical energy is provided by PSH systems only (over 99% in Europe and worldwide [6]). Used onshore, this well-established technology has outstanding features, but is restricted to mountainous regions with water resources that are readily available. BE transfers the PSH key features to an offshore environment. It can be used in a decentralized and distributed way close to offshore renewables, is very effective, durable and robust. The BE concept is very flexible. It can be applied both in "shallow" water, where wind turbines typically are bottom mounted and in deep water, where floating wind turbines are required. For deep water conditions BE can be realised either in the form of platforms (preferably multipurpose platforms) or even directly within the structures of floating wind turbines. In addition to rough offshore conditions BE is well suited for inland

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application, too. Floating energy storage structures could become reality in lakes, abandoned and flooded opencast pits or even in quarry ponds. In combination with the possibility of multifunctional use of the BE device this high flexibility in potential locations offers interesting benefits towards other storage solutions.

To sum up BE has the potential to enable an optimized integration of renewable energy sources (Fig. 1). As a consequence, significant positive effects on the regional and wider-ranging infrastructure for electricity supply can be expected.

3. Concept and technology

3.1. Basic concept

The major differences compared to conventional PSH technology are the basic arrangement and the location of the reservoirs. While conventional PSH systems consist of an upper and a lower reservoir, BE uses a smaller reservoir (the inside space of a floating structure), located within a larger reservoir (the sea or a lake). Water can be moved from one reservoir to the other by means of pumps and turbines or a pump-turbine (Fig. 2). The required head (the height difference between an upper and a lower water level) is defined by the mass *m* and the shape of the floating structure. The inside space of the structure serves as lower reservoir.

A pump-turbine is installed in the lower part of the structure. Water is pumped from the inside space of the structure to the sea to store energy. As a consequence, the structure becomes more buoyant and moves up (Fig. 2b). Allowing water to flow back into the structure drives the turbine, generates energy and lowers the structure (Fig. 2a). Typically, the pressure head remains approximately constant all the time.

BE is a robust system with a floating platform built from a suitable construction material, typically concrete. Floating concrete structures are economical to build and maintain. The existing offshore industry (oil and gas) as well as coastal construction industry (e.g. submerged tunnel construction) have a lot of experience with large floating concrete structures. While mass is a disadvantage for many floating structures, it is an essential quality in this case. The structure mass and the geometry ensure an appropriate immersion depth. Therefore, the water level inside is significantly lower compared to the outer sea level. The water level difference defines the available pressure head and is a decisive parameter for the pump-turbine system. Both, the inside

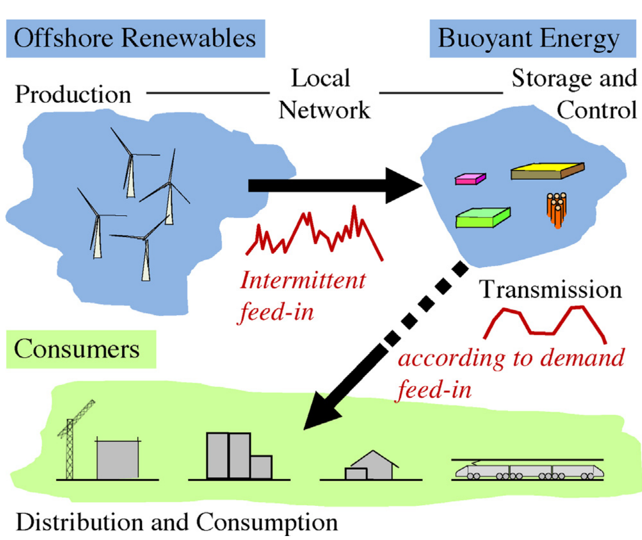

Fig. 1. Buoyant Energy (BE) – Typical value chain.

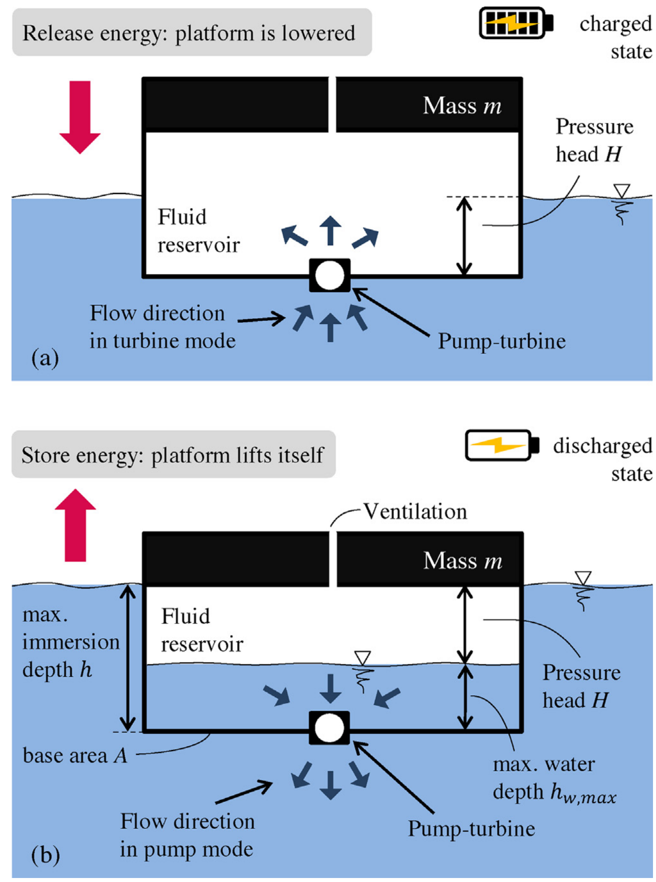

Fig. 2. Basic technical concept, (a) Energy production, (b) Energy storage.

fluid reservoir volume and the head difference are critical parameters determining the energy storage capacity of BE systems.

Structure mass as well as geometry contributes to better wave damping properties. The exploitation of knowledge from the offshore industry guarantees high durability of the concrete floating structure. Safety is an outstanding issue of this system. Research is required to ensure floating stability and station keeping during operation under different metocean conditions. Research activity has to be supported by physical model tests to validate empirically or physically calculated results as well as numerical simulation models.

3.2. The “light” BE version

The main distinguishing feature of the “light” BE version is, that the water level of the larger reservoir (typically the sea) is located below the water level inside the BE storage facility (Fig. 3). In contrast to the original concept the direction of energy conversion is reversed. For this purpose, “light” BE systems are equipped with buoyant bodies situated underneath a fluid reservoir, which raises the bottom of the fluid reservoir above the water level of the outer reservoir. In turbine operation mode (Fig. 3a) the floating structure rises, working against gravity. The potential energy is converted into electric energy and released. In pump operation mode (Fig. 3b) the floating structure moves down, thereby converting excess electric energy into potential energy and storing it. The “light” BE version benefits from light construction material, which could result in significantly reduced investment costs compared to the “heavy” original BE solution. Even the use of flexible fabric material could be a potential option. Anyhow, most probably there will be more stability problems due to the relatively high elevation of the