Ocean Engineering 165 (2018) 328–335

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

A floating energy storage system based on fabric

Robert Klar*, Bernd Steidl, Markus Aufleger

Unit of Hydraulic Engineering, Faculty of Engineering Science, University of Innsbruck, Technikerstraße 13, 6020 Innsbruck, Austria

ARTICLE INFO

Keywords:
Hydraulic energy storage
Fabric
Offshore
Decentralised
Air compression
Floating pumped storage

ABSTRACT

This paper focuses on the theoretical investigation of the 'light' version of the Buoyant Energy (BE) storage concepts. Generally, BE transfers the pumped-storage hydropower key features to an offshore environment. The 'light' BE version is characterized by a lower water level of the surrounding water compared to the inner water level of the energy storage device. Therefore, it benefits from light construction material. Maybe the most lightweight construction method is the use of waterproof fabric material. First, the basic design aspects and ideal storage capacities of the original 'light' BE concept using rigid reservoirs is assessed. Second, a new design approach based on fabric is introduced. After describing and discussing its main components, the underlying equations are applied to form an exemplary energy storage device with 5 MWh capacity. Third, a design approach for increasing the energy storage capacity of airproof 'light' BE systems by added air compression to increase the pump-turbine head is presented. Fourth, floating stability aspects of 'light' BE devices are highlighted based on two exemplary box shaped designs. The results indicate that the ideas for using fabric as a construction material are promising and should be subject to further studies.

1. Introduction

1.1. Background

The need of more energy storage capacity to compensate imbalanced supply and demand in future renewable energy grids is widely accepted. Therefore, several storage systems are under development and compete with each other. Promising examples are the Tension Leg Platform integrated Hydraulic Accumulator (Buhagiar and Sant, 2017), the StEnSea subsea energy storage technology (Henning et al., 2017), Ocean Renewable Energy Storage (Slocum et al., 2013), Energy Bags for underwater Compressed Air Energy Storage (CAES) (Pimm et al., 2014) and Constant Pressure Accumulators for Offshore Wind Turbines (Saadat and Li, 2012).

Buoyant Energy (BE) (Klar et al., 2017) is a floating hydraulic energy storage system. In essence, it consists of large and floating reservoirs and hydraulic pump-turbine/motor-generator systems for energy conversion. In a charge-discharge cycle, electrical power is converted to gravitational energy and back again. BE is suitable for nearshore and offshore storage needs and uses the well-established technology of pumped-storage hydroelectricity (PSH) in a new arrangement.

The exploratory project 'PrepareBE' (Klar et al., 2016), which ended in October 2017, clarified its technical feasibility and economic viability. Furthermore, the project determined the most promising application fields and defined development goals with the best chances of success. Buoyant Energy benefits from its simple architecture and high adaptability to local boundary conditions. It provides unlimited number of load cycles, short response times, high operation efficiency and multi-use space on the platform roof and inside the structure for e.g. wind farm operation, transport, industry, leisure, accommodation or aquaculture.

1.2. Basic 'light' BE concept

One of the BE concepts is characterized by a lower water level of the surrounding water compared to the inner water level of the floating energy storage device. For this purpose, a fluid reservoir is equipped with buoyant bodies as shown in Fig. 1. In turbine operation mode water flows from the fluid reservoir to the surrounding water, driving a turbine. The floating energy storage platform rises and the stored gravitational is converted into electric energy. In pump operation mode the floating structure moves down, thereby converting electric into potential energy and storing it. A lightweight construction is advantageous compared to the use of heavy materials for a platform structure. Therefore, it is called the 'light' version of BE.

* Corresponding author.
E-mail address: robert.klar@uibk.ac.at (R. Klar).

https://doi.org/10.1016/j.oceaneng.2018.07.051
Received 28 December 2017; Received in revised form 15 May 2018; Accepted 19 July 2018

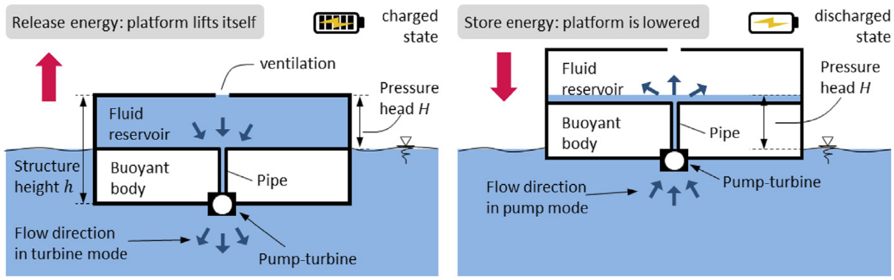

Fig. 1. Schematic sketch of the 'light' version of Buoyant Energy in charged (left) and discharged (right) state.

1.3. Basic design aspects and ideal storage capacity

The 'light' BE version benefits from light construction material, which could result in significantly reduced investment costs compared to the 'heavy' BE solution (Klar et al., 2017). The use of flexible fabric material could be a potential option and is discussed in section 2. Due to the relatively high elevation of the centre of gravity compared to the center of buoyancy, the floating stability especially in bad weather and sea conditions has to be considered carefully (section 4). For that reason, low and wide structures providing sufficient form stability could be favourable.

The useable energy content of a 'light' BE energy storage system depends upon the shape of its fluid reservoir, buoyant body and its mass (structure, technical equipment). An idealized BE system (Figs. 1 and 2) is used to show the functional relationship. Fluid reservoir and buoyant body are shaped cylindrically and share the same base area A. The wall thicknesses t are considered infinitely thin. Fig. 2 shows three schematic sketches of ideal BE devices each one with different fluid reservoir volumes $V_{A,i}$ and heights $h_{A,i}$, buoyant body volumes $V_{B,i}$ and heights $h_{B,i}$ and pressure heads H_i.

The following equations (1)–(5) describe boundary conditions and functional relationships, which characterize such ideal BE storage systems. The used equation symbols are the water density ρ_w, the gravitational acceleration g, the pressure head H, the flow rate Q, the filling time t_{max}, the power P and the energy storage capacity W.

$$A = const. \;\mid\; Q = const. \;\mid\; h = h_A + h_B = const. \tag{1}$$

$$V_A + V_B = A \cdot h = A \cdot (h_A + h_B) \text{ with } V_A = A \cdot h_A \text{ and } V_B = A \cdot h_B \tag{2}$$

$$t_{max} = V_A / Q \;\mid\; H = h - h_A = h_B \tag{3}$$

$$P = \rho_w \cdot g \cdot H \cdot Q \tag{4}$$

$$W(t_{max}) = P \cdot t_{max} = \rho_w \cdot g \cdot H \cdot V_A = \rho_w \cdot g \cdot (h - h_A) \cdot A \cdot h_A \tag{5}$$

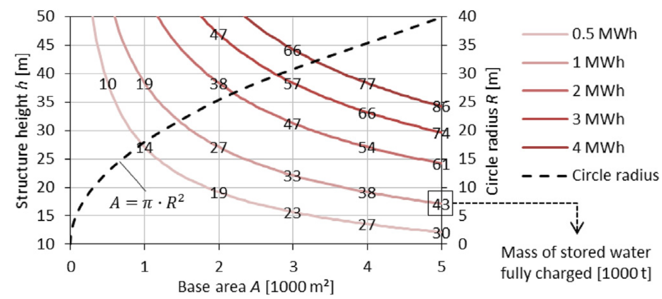

Fig. 3. Optimal energy storage capacity as a function of structure height h and the base area A.

For each BE system of Fig. 2 the specific storage capacity can be calculated according to equation (5). The optimal height $h_{A,opt}$ to maximise the energy capacity $W(t_{max})$ for a given structure height h and base area A is derived from the following equation:

$$dW/dh_A = 0 \rightarrow h - 2 \cdot h_{A,opt.} = 0 \rightarrow h_{A,opt} = h/2 \tag{6}$$

As a result, the storable energy content reaches its maximum, when the heights of fluid reservoir and buoyant body correspond to half of the structure height h and the pressure head H (equation (7)). The optimal energy capacity $W_{opt}(t_{max})$ of an idealized 'light' BE system is expressed by equation (8) and illustrated in Fig. 3.

$$h_A = h_B = h/2 = H \tag{7}$$

$$W_{opt}(t_{max}) = \rho_w \cdot g \cdot A \cdot h^2/4 = m \cdot g \cdot h/2 \tag{8}$$

The volumetric energy density ρ_{vol} in fully charged state is:

$$\rho_{vol} = W_{opt}/V_B = W_{opt}/(A \cdot h_B) \tag{9}$$

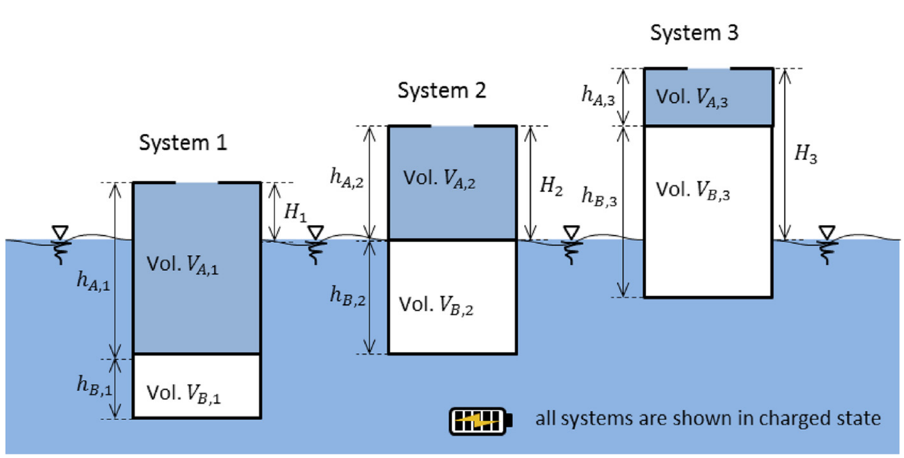

Fig. 2. Schematic sketches of three 'light' BE systems with the same structure height h and base area A but different fluid reservoir and buoyant body volumes (pump-turbine and technical equipment is not shown).