Sink Float Solutions

Assessing the feasibility of an Energy Storage Solution

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Abstract

Renewable energies sources are increasingly present on the Belgian ground for electricity production. They provide fluctuating output powers due to climatic conditions (solar panels and wind turbines) and therefore require energy storage solutions, in order to maintain stable energy levels, like traditional power plants. Energy storage allows furthermore to control the power consumption overall and reduce the electricity cost by providing balanced electricity levels (store surplus energy, manage the increase of intermittent energies), temporary solutions to faults, etc... [1]. The Sink Float technology consists of using concrete masses that are shifted on large depths underwater to generate/recharge energy from/to a neighbouring renewable energy source. The aim of this article is to present the recent Sink Float technology and assess its feasibility as a worldwide solution for energy storage at low cost.

1 Energy Storage in Belgium

Electrical energy is stored by converting it into other forms e.g. potential, thermal, chemical or kinetic. The seven most widely used storage technologies are the following: Pumped Hydro Energy Storage (PHES), Compressed Air (CAES), Flywheel, Conventional Batteries, Fuel Cell (FC), Hydrogen Storage, and (Super)Capacitor [1]. In Belgium, only the PHES is operational in Coo-Trois-Ponts, and its functioning principles will be briefly explained in the following paragraph.

Currently used in more than 99% of the worldwide storage capacity networks for energy storage [1], the PHES is a cost effective solution that is mostly used for large scale storage, by the means of two water reservoirs at different heights linked by a reversible pump-turbine and motor-generator set that enables both charging and discharging mode. PHES is able of storing hundreds of MW (power) and MWh (energy), has discharge times from hours to few days and 70-85% efficiency [1][10]. The disadvantages are the costly construction time, long delays to switch between charge and discharge (due to the large water inertia) and dependency on appropriate geographical reservoirs [6]. In Belgium, the installation provides 1100 MW of power for five hours, totaling over 5 GWh of energy. During winter days in Belgium, the required power load can peak to 14000 MW [10]. This represents an important challenge in the design of appropriate energy storage levels for efficiency and economic reasons. A project of extending the already existing PHES infrastructure in Belgium is under development with a goal of increasing the energy storage capacity by 50% [3].

Two optimization goals arise:

1. Dampen power fluctuations on the short short-term
2. Make maximal profit on the long-term, in addition of the main need for larger capacity energy storage cells.

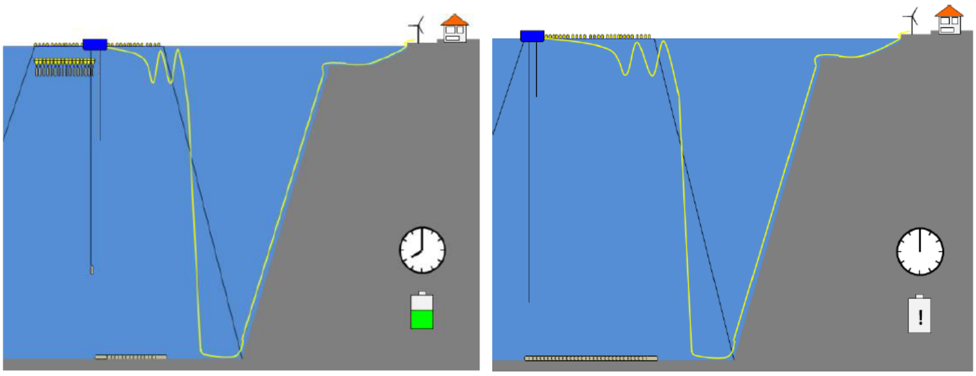
The actual storage solutions are and will always remain costly.

2 Presentation of the Sink Float Technology

Sink Float technology presents itself as an alternative that is ten times less expensive than the already-existing storage systems. It is based on the working principle of a huge underwater battery. Since 2013, Sink Float Solutions is growing in maturity through R&D, design and optimization and market analysis [11].

2.1 How it works

The technology uses potential energy that is generated by the height difference between the water surface and the available underwater depth. The functioning principle requires concrete blocks, acting as mass loads, that are vertically shifted, under the water level, by a hoist system installed on a barge, and depicted in Figure 1. Electrical energy is produced in generator mode (Figure 1a), when all the concrete loads descend from the water surface to the water depths. The excess energy, produced by renewable sources, is used to recharge the system, in motor mode (Figure 1b), and bring the loads back to the surface. In both generator and motor mode, the loads are being shifted one after the other [11].



(a) Loaded sink float (generator mode) (b) Unloaded sink float (motor mode)

Figure 1: Sink Float technology

As opposed to the already existing and working PHES system, that uses height differences of 200m between the two water basins, the Sink Float design is moving loads over 2000 to 4000 m deep, which are free and available areas in most seas oceans [11]. Such depths make possible to store as much energy in one ton of concrete than in one ton of a conventional battery, which makes the Sink Float solution a very cheap alternative to an already existing costly and inflexible technology.

The figure below quantitatively compares the produced energy and price per kWh for the two main actors in the energy storage domain [10], as well as the estimated amounts that the Sink Float technology proposes [11][12]. As announced and adverted, Sink Float offers incredibly lower prices and an impressive flexibility in the energy storage capacitance, in addition to the interesting trend for which storing more energy is less costly per unit energy.

2.2 Technical challenges

Firstly, exceptional weather conditions have to be taken into account in any offshore technology design. Maintaining the heavy concrete loads at a stable position at the surface during thunderstorms and turbulent weather requires long and robust steel cables that are too costly with an anchor-float system. A solution has been designed as underwater anchor float system, that requires less robust cables, and in a lower amount, since there is no stabilization needed underwater when the climate is troubled. Such a design is shown on Figure 3a, where the concrete blocks are shown on the right-hand side of the image, being stocked at their highest height under the water level, instead of at the water surface, on the left part. All the underwater anchor floats are linked to the same platform (Figure 3b) and such a system

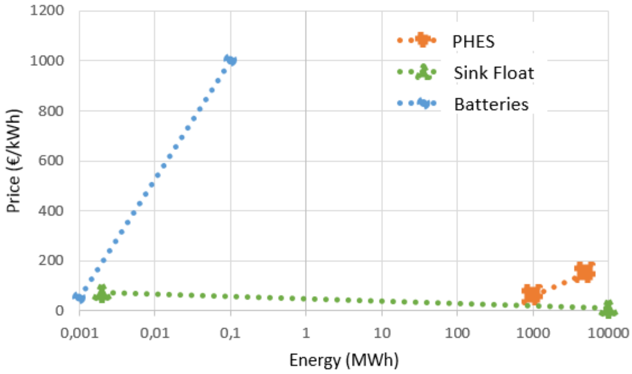
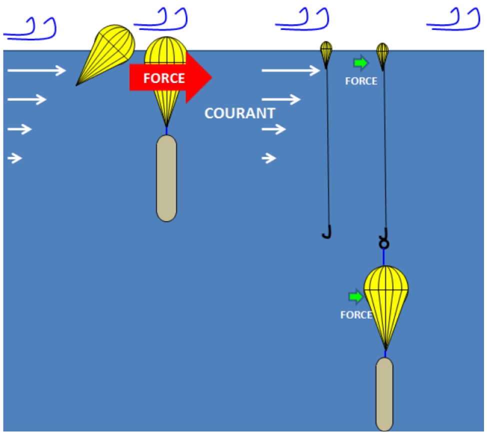


Figure 2: Energy storage solutions - Cost and storage capacity [10][11]

is very interesting for its lower cost. Taking these upgrades into account, the overall system (floaters, anchor cables, hoist and 4000 m cables, hooking set-up and loads movement control) proposes an investment cost that is ten times lower than the one for classic batteries offering the same storage capacity [11].



(a) Fully underwater solution

(b) Pontoon

Figure 3: Sink Float technology [11]

Secondly comes the issue of sufficient ocean depth at proximity of the renewable sources whose power has to be stored. At a too large distance from large ocean depths, when the distance between the Sink Float system and the linked renewable energy source reaches a few hundreds of kilometers (at the centre of the American continent for instance), the price of transmission cables becomes problematic. The proposed alternative is to use giant pumped-storage hydroelectricity – which consists of PHES but at larger dimensions than the conventional PHES installations, and which also have the advantage of not requiring a mountain-type geography, as it can be built on flat grounds. This is made possible by the conical shape of the drilled hole, which allow to perform an economy of scale. In other words, multiplying the dimensions of the drilled holes by a given factor allows to divide the cost of energy production per investment by the same factor [5]. However, such a concept requires massive flat areas (typically at least 800 m deep to become more interesting than a conventional battery solution). At this stage, only already existing mine fields would avoid over a decade of construction.

Finally, the most important challenge, is the Sink Float system position at sea. There is a trade-off between the underwater depth and the electricity cables length between the station and the renewable energy source [8]. Indeed, the largest amounts of energy storage are made possible by large depths, where only large depths can be reached far away from the coast, hence from the renewable energy source. This might constitute the main, and maybe fatal issue in the Sink Float design, since the high price of transport cable is an economic bottleneck that does not present favorable changes in the future.

2.3 Project maturity

As seen in the previous sections, a prototype has been designed, calculated and optimized. The orders of magnitudes that have been presented widely (TEDx conference [12], LinkedIn SlideShare [4], website [11]) are the following:

One weight is labelled as a block of a thousand cube meter of concrete - where one cube meter of concrete has a mass of 1200 kg underwater. Such a mass (1.2 kt[1]) will produce 13MWh at 4000 m of depth, by the potential energy formula that is given in Appendix B. According to the Sink Float designers, an underwater platform made of a barge, a hoist system, multiple pontoons on which the weights are stocked, can be up-scaled and developed to sustain for up to 20 to 40 000 GWh for worldwide energy storage.

The cost study is thorough and exhaustive [11], taking into account all the components maintenance and installation. The market has been assessed, varied combinations of energy production and storage have been simulated and compared at a small scale. Risks have been analyzed in many aspects (economic, commercial, patents, feasibility, industrialization), and a business plan has been created to launch the prototype installation and testing at different scales and depending on the amount of collected funds.

A Business model was synthesized and modelled for an investment budget of one million euros in the first year, topping to two to six millions over 5 years. In the pie chart below, the "Demos" label consists of two prototypes (1 ton and 20 tons at 2000 m depths) to be built and tested in the Mediterranean Sea. The investments will be allocated as shown below, and C. Stevens predicts a capital gain of ten times the initial investment within the first year [11].

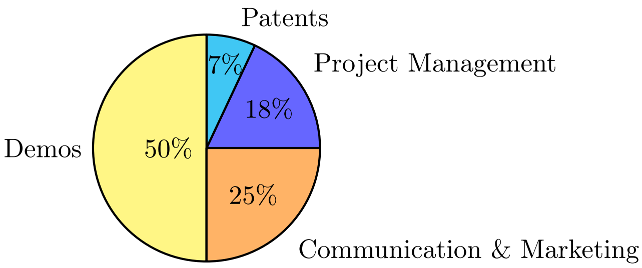


Table 1: Investments

3 Future perspectives and conclusion

Sink Float Solutions is looking for key partnerships, customers as well as suppliers. They have a starting fund of about 250k€ [11] since 2015 and have filed patents since 2013. According to C. Stevens, the founder of Sink Float Solutions, the technology has been presented to the Industry and Energy ministries of several countries in Europe [12]. The economical hypotheses and feasibility have not been questioned. However, the European minister's mentality appears to be skeptical about low-cost clean solutions to substitute thermal and fossil back-ups that are presently used complementary to renewable energies.

From the Sink Float Business Plan, it appears that two patents out out the four initially delivered have been filed and guaranteed until 2032 for the technology [11]. There is thus progress to be done in this matter before having the Sink Float technically validated. The Business Plan is at the present stage an explanatory document over the Sink Float design, development and its financial parameters.

[1] kt = kiloton

A major next step would be to create an academic-type report that can be used as reference for any major investor, supplier, governmental institution and/or academic partner. It is indeed necessary to have rigorous justifications, references to all the external sources and a unified statement over each of the aspects of the technology. In other words, a unique yet complete model to assess the gains and benefits of the Sink Float regarding its dimensions and parameters. For instance, a thorough simulation of a Sink Float technology implanted on an island could be detailed and illustrated - in terms of installation, position, dimensions and the amount of cities it could provide with clean and low cost energy, as it is the end goal of the Sink Float project.

A last but not least future work is about changing the perspective of governments and the overall population regarding fossil fuels. As an illustrative example, Table 2 shows the amounts of energy that are produced per kilo of burnt fuel and gasoline[2], compared to one ton of concrete blocks within the Sink Float technology. The thousand factor difference between the fuel and gasoline versus the concrete comes from the nature of the energy production - fuel and gasoline are made out of a chemical combustion reaction, whereas the concrete is only but a mass being dropped over a given height. As a reminder, over a ton of concrete block underwater is obtained in a meter cube, taking the Archimedes' principle into account (see Appendix B). These results provide a very interesting insight into the possibility of suppressing the polluting and environmentally dangerous energy production means, since there is a green and easy way of producing as much energy with a main component of unlimited resource.

Fuel	44 MJ/kg
Gasoline	42 MJ/kg
Concrete at 4000 m depth	39.24 kJ/kg
Concrete at 4000 m depth	47.1 MJ/m^3

Table 2: Comparing the generated energy per kilogram of element (OECD)

Despite the fact that this way of producing energy is polluting and dangerous, it is still the most widely used source in the world and its total cost for energy production is very low, even though C. Stevens has found a combination of wind turbines, and Sink Float solution could provide a cheaper alternative to the already existing polluting energy and used batteries, as can be seen in Table 3.

Fossil Fuels	0.85 €/kWh
Sink Float + Wind turbines	0.77 €/kWh
Lithium-Ion batteries	1.68 €/kWh
Lead-Acid batteries	3.07 €/kWh

Table 3: Levelized costs of energy storage [9][11]

As a conclusion to this article, the Sink Float project can be summarized as follows: the technical content is promising thanks to its great simplicity, robustness, and durability. The future step is to gather funds (two scenarios are set for the different sums acquired, as mentioned in Section 2.3) and start building a prototype to actively test the project and provide actual results. Instead of requiring millions of investments, Sink Float can start to design and build a 10 MW prototype in an island area (Canary Islands, Réunion Islands, New Caledonia,...), starting with half a million of funds. The goal is to be technically validated by governments and energy leaders, before being launched and bring a clean and low-cost solution to renewable energy storage.

[2] https://stats.oecd.org/

A Brief state of the art of the energy storage technologies in the world - other than PHES

- **CAES**: Excess energy activates an air compressor, whose produced heat is captured by a thermal storage unit. Energy is (re)generated by the expansion of the excess heat in a turbine. The air used in CAES is natural and free, however the charge and discharge transition takes several minutes and the system depends highly on geographical-based natural formations [1].
- **Flywheel**: The use of a rotating heavy mass allows to generate high kinetic energy to charge an electrical generator. However, flywheels cannot be used for the massive energy capacities we are interested by (at the scale of a country electrical distribution), even though they are gaining more and more applications in the automotive and rail industry [1].
- **Battery**: Converting electricity into chemical energy within rechargeable batteries is a fairly recent technology that is limited in the storage capacity while being costly and requiring high maintenance.
- **Fuel Cell**: They are costly in terms of production, transportation and storage, as it uses hydrogen in a chemical reaction to produce electricity.
- **Hydrogen storage**: Hydrogen is an abundant element that can be used as electricity storage medium, however the needed molecular hydrogen still requires R&D for H_2 production [7].
- **(Super)capacitor**: This electrical charges storage system, made of two conductor plates separated by a dielectric. Unfortunately, the amount of electrical energy to be stored in a capacitor is proportional to its capacitance, and the square of the charging voltage, which are limited in the conductor's geometry (from there arise manufacturing issues) and the upper voltage limit of the dielectric, respectively [2].

	Pumped hydro Storage in the form of water contained in two reservoirs at different levels	Large CAES Storage by compressing air in underground salt caverns	Hydrogen Storage in the form of hydrogen produced by fuel cell via water electrolysis	Convent. Batteries Storage through a reversible chemical reaction in chemical energy	Flow Batteries Storage through a reversible chemical reaction between two electrolytes	Advanced Batteries Storage through a reversible chemical reaction in chemical energy	Flywheel Storage in the form of kinetic energy by rotating a mass around an axis	SMES Storage in a magnetic field by injecting DC current into a superconducting coil	Supra-capacitors Storage in an electrostatic field between a pair of charged plates
Power (MW)	100 -5000	100 -300	0,001 - 50	0,001 - 50	0,003 - 7	0,001 - 50	0,002 - 20	0,001 - 10	0,01 - 1
Energy (MWh)	> 1000	100 - 1000	1 - 1000	0,001 – 0,1	0,001 – 0,1	0,1 - 100	0,001–0,01	< 0,01 kWh	< 0,001
Efficiency rate	70 – 85 %	50 – 75 %	< 50 %	60 – 95 %	70 – 85 %	85 – 100 %	85 – 95 %	+/- 99 %	> 95 %
Discharge time	Hours	Hours	Hours	Minutes	S - hours	Hours	Minutes	Minutes	Seconds
Power costs (€/kW)	500 - 3600	400 - 1150	550 - 1600	200 - 1000	500 - 2500	700 - 2000	100 - 300	100 - 400	100 - 400
Energy costs (€/kWh)	60 - 150	10 - 120	1 - 15	50 - 1000	100 - 1000	700 - 2000	1000 - 3500	700 - 7000	300 - 4000
Maturity level	Mature	Project	R&D	Project - Mature	R&D	R&D - Project	Project	R&D	R&D

► Focus on innovations

	Pumped hydro		Large CAES	
	Sea water PHS	Underground PHS	Adiabatic CAES	Isothermal CAES
Innovation	Instead of a source of fresh water (lake, river), the lower reservoir is the sea and these systems pump salt water from the ocean to a land reservoir above.	Using underground locations such as old unused mine to act as the second reservoir, and the space above the mine as the highest reservoir	The system captures the heat resulting from compression and stored it in order to reuse it for expansion process	Capture heat with spilled water, store water and reapply to the air for expansion process. Air is compressed using standard steel pipes upper ground.
Location	Japan (exploitation)	USA, United Kingdom (investigation)	Germany, France (investigation)	USA, Unit, Switzerland (investigation)

Figure 4: Current storage technologies and their quantitative features

B Energy production formula for the Sink Float Technology

The energy that is produced by the Sink Float technology is of potential nature and is computed according to the law

$$E_p = mgh \quad (1)$$

Where E_p is the potential energy expressed in Joule (J), m the mass of the concrete block that is shifted underwater, expressed in kilograms (kg), g the gravitational constant (9.81 ms^{-2}), and h the underwater depth (or height) on which the mass is being shifted, expressed in meters (m). We are also using the correspondence for which 3600 J = 1 Wh, we can easily compute the produced energy in MWh for a given mass of concrete underwater, m. The Archimedes' principle has to be taken into account, as a mass of concrete has a lower apparent mass underwater: a cube meter of concrete has a 2200 kg mass on the ground, and 1200 kg underwater (sea) [12].

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