BUOYANT ENERGY

DECENTRALIZED OFFSHORE ENERGY STORAGE IN THE EUROPEAN POWER PLANT PARK

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INTRODUCTION

Climate change. Ecological Footprints. Solar Power. Energy Systems. These are all words or phrases that seem to be in just about every newspaper at least every other day. This poses one question: why?

Because these days more and more new motions are being passed, which are regulating the use of renewable energy sources. If renewable energy sources should be used as much as the European Union would like them to be used by 2020, something has to change. Renewable energy sources are intermittent, which means that their energy output never equals the energy demand at that time. Consequently there will be times of energy excess alternating with times of energy shortage. The balance between energy supply and demand is a prerequisite for any stable energy system. This is where the new and highly efficient energy storage system *Buoyant Energy* comes in.

There are various storage technology approaches that have been designed over the years for many differing fields, but in hindsight certain economic and technical drawbacks have come to light, such as issues with cost, topographical requirements, economic and energy storage efficiency as well as their current stage in development. The brand new principle of *Buoyant Energy* has been developed to overcome such flaws, as have been seen in all storage systems to date.

Buoyant Energy, a floating hydraulic energy storage system, is based on the well-established technology behind pumped energy storage systems. Floating platforms – arranged individually or in clusters – can be located close to offshore wind farms, like in the European North Sea, or any offshore site, where decentralized compensation of fluctuating power generation is needed.

INCENTIVE

The production of electricity from renewable sources is highly unstable, especially as wind and solar energy, and hydro power strongly depend on weather and climate conditions. The things that make today's power system so unusually unique are its unpredictable demand and the irregularities in the inputs to the general power grid. As these two things obviously go hand in hand, some adjustments are required, which include more efficient storage systems.

Within the European Union the percentage of renewable energy sources in relation to the annual gross energy consumption was at 8.5% in 2008. As of 2009 every EU member state had a new goal: to increase the use of renewable energy sources, so that the EU as a whole will reach a total of 20% by the year 2020, also known as the 20-20-20 Directive (Directive 2009/28/EC). Germany's percent of energy generation from renewable energy sources has increased from 3.1% in 1990 to 17.1% in 2010 (BMU, 2011[1]). The main renewable energy sources in 2010 were wind (6.2% of total electric production), hydropower (3.4%), biogas (2.4%) and solar power (1.9%) (BMU, 2011).

While the planned construction of large offshore wind energy capacitances in the European North and Baltic Seas, as well as the repowering of existing onshore wind turbines, may increase the power generation capacitances in the north-eastern provinces of Germany, there is still the issue of what to do with the newly produced energy, that can't be stored. The aforementioned provinces of Germany lack the topographical qualities necessary for the construction of conventional pumped storage plants. All of the extra power transmission necessary for the adequate storage of the additional energy in pre-existing storage plants would put extensive pressure on the existing power grid. According to the *dena* Grid Study I (2005[2]), about 14 GW of additional storage capacity will be needed in Germany by 2020.

BASIC PRINCIPLE AND VARIATIONS

The basic principle of *Buoyant Energy* (buoyant hydraulic energy storage system) is quite similar to that of pumped hydropower storage plants; however the major difference is the arrangement and location of reservoirs at such plants. While conventional pumped hydropower storage plants consist of an upper and a lower reservoir, *Buoyant Energy* uses a smaller reservoir, that floats within a larger reservoir (see Figure 1). Water can be moved from one reservoir to the other by means of pumps and turbines. The structural shell of the water reservoir should be made of as much concentrated mass as possible.

The energy is stored solely through the potential energy of the mass of the floating structure. In order to store energy, water from within the smaller reservoir is pumped to the larger reservoir (pump mode). As a result, the floating structure that encloses the smaller reservoir rises. In order to release the energy, the structure is lowered and the inflow into the smaller reservoir powers a turbine (turbine mode).

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[1] BMU – Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [Germany]
[2] German Energy Agency, Integration of Onshore and Offshore Wind Energy into the National Grid by 2020

The large reservoir could be any large body of water, such as a lake, the sea or even the ocean. One highly beneficial possible utilization of *Buoyant Energy* would be to arrange the afore mentioned floating structures in the vicinity of the offshore wind farms in the North Sea, where a large storage capacity is needed, due to the highly irregular energy generation.

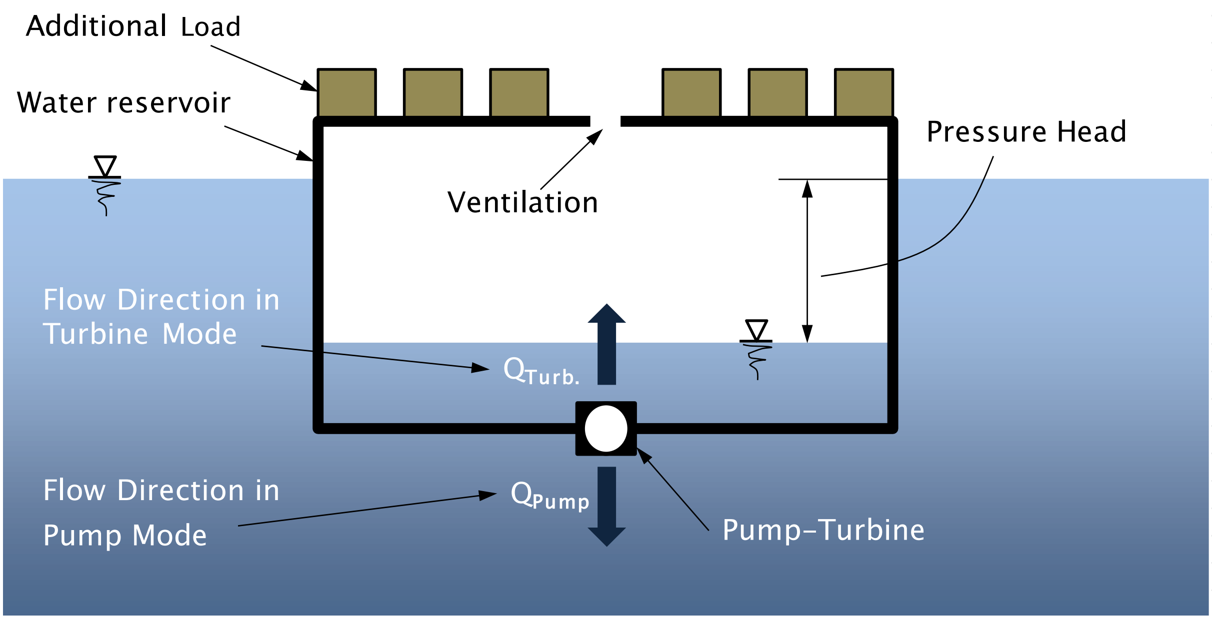

Figure 1: Buoyant Energy's Basic Principle

There are four different variations to the design that do not affect the functionality or change the basic principle of *Buoyant Energy*.

Variation 1: Flexible Mooring Lines

Variation 1 realizes the possibility of replacing part of the mass with flexible mooring lines (see Figure 2). They would act contrary to the lateral displacements of the water; in doing so, stabilize the horizontal position of the platform. The addition of mooring lines to the basic principle does not change the way the pumps and turbines work. The device stores energy in pump mode and releases said energy in turbine mode.

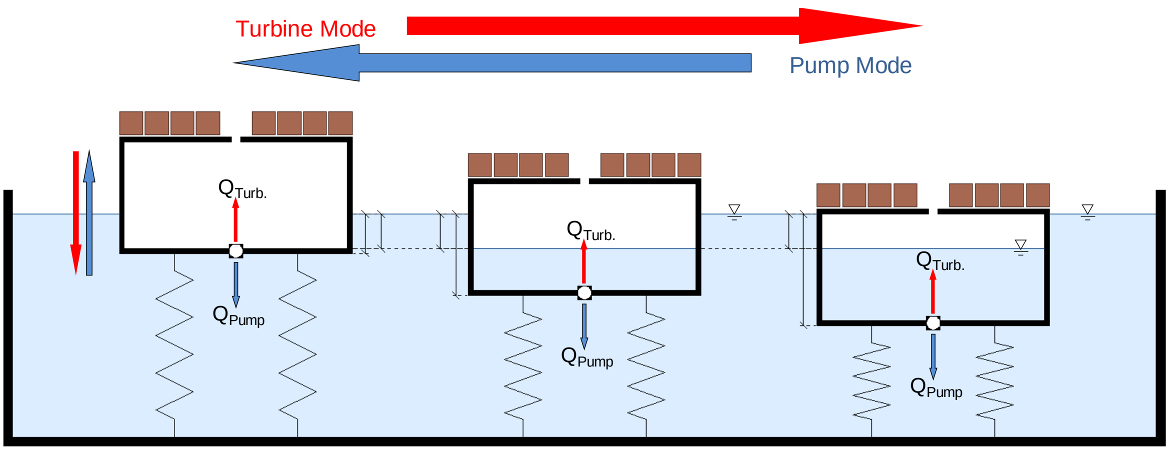

Figure 2: Basic Principle of Variation 1

Variation 2: Mooring Lines Attached to Buoys

In variation 2 a part of the potential energy is stored by highly buoyant bodies which are connected to the floating platform by mooring lines that are redirected over the seabed (see Figure 3). This mechanism acts as a stabilizer just as the mooring lines in variation 1 do. Again, the functions of the pumps and turbines do not change.

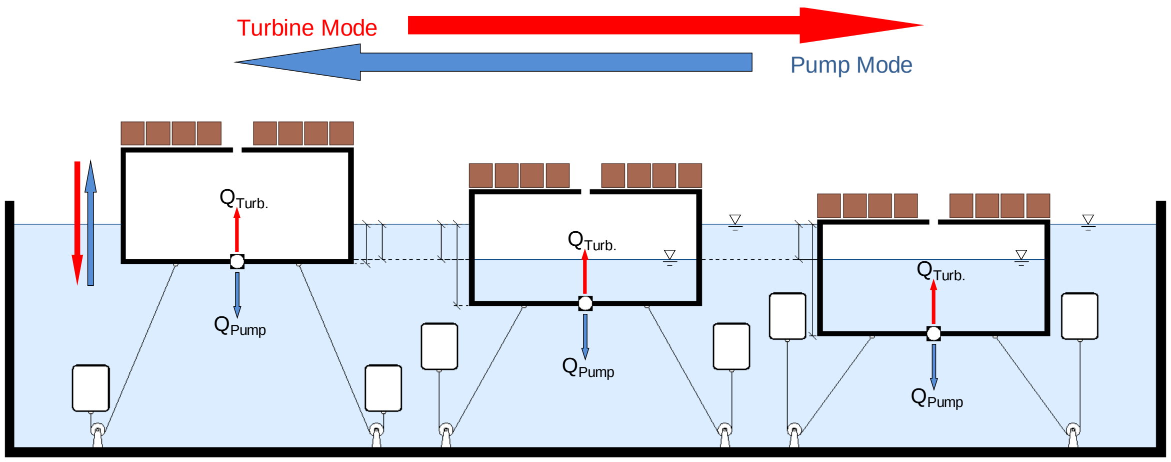

Figure 3: Basic Principle of Variation 2

Variation 3: Reversed Energy Conversion

Variation 3 shows an alternative in which the water level of the larger reservoir is below that of the inner reservoir. In contrast to Variations 1 and 2, the direction of the energy conversion is reversed. For this purpose the hydraulic energy storage plant is equipped with buoyant bodies within the structure and underneath the reservoir, which raise the bottom of the water reservoir above the water level of the outer reservoir (see Figure 4).

In this case the flow direction of the water does not change; the direction of the energy conversion is reversed. In turbine operation mode the floating structure rises, working against gravity. The potential energy is converted into electric energy and released. In pump operation mode the floating plant is lowered, thereby converting the electric energy into potential energy and storing it.

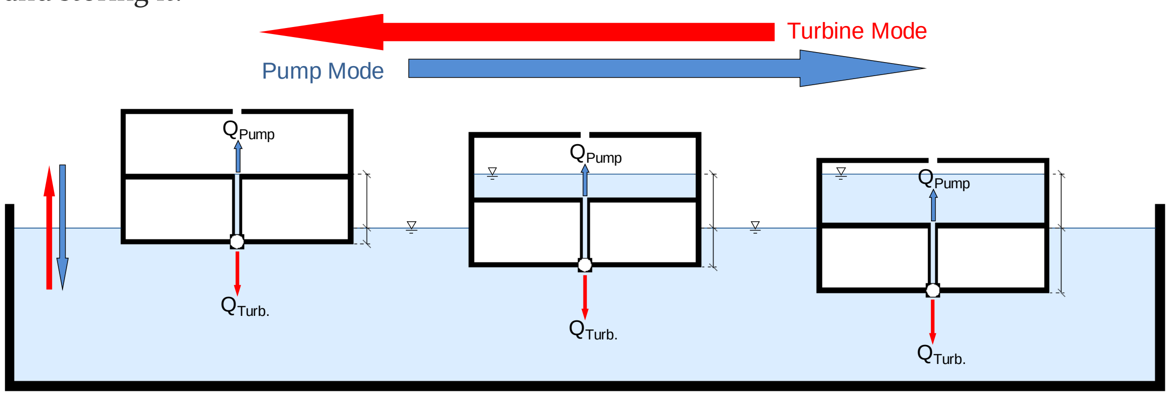

Figure 4: Basic Principle of Variation 3

Variation 4: Air-Tight Reservoir

Variation 4 is similar to variation 3 in many ways. Turbine and pump modes function in the exact same way and they both have buoys of sorts built into the lower half of the structure, which put the water level of the smaller reservoir above that of the body of water that encloses it. And just like variation 3, variation 4 contrasts variations 1 and 2 in that the direction of the energy conversion is reversed. The main difference between variations 3 and 4 is that the water reservoir in variation 4 is sealed air-tight (see Figure 5)

During pump operation mode an extremely flexible material is deformed, in relation to the water pressure inside; the plant is lowered into the water. As a result the potential energy, now deformation energy, can be stored and then released again in turbine operation mode, when the contraption rises as the flexible material expands. The flexible material in its most basic design can be realized as an air cushion.

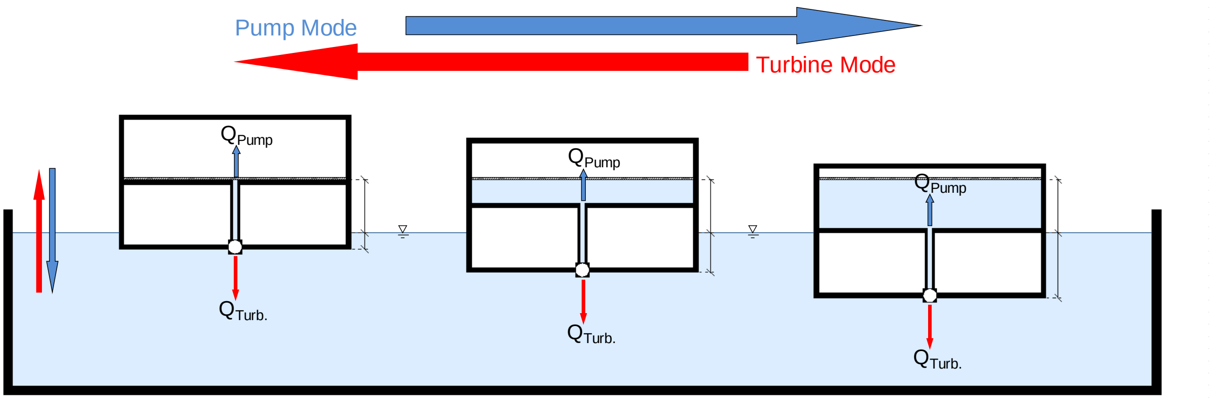

Figure 5: Basic Principle of Variation 4

UNIQUE TRAITS

The concept behind *Buoyant Energy* storage plants is very unique. There are many aspects that make this design on of a kind. However, similar structures like concrete ships and immersed tubes *have* been built before, albeit for other purposes. Because of this, well tested and proven construction methods for the outer shell are already available. Contrary to the main focus of modern shipbuilding, which is lightweight construction, robustness and great mass are crucial components for a floating hydraulic energy storage plant.

Diverse Combination Possibilities

As the demand for offshore energy, aquaculture and transport infrastructure (e.g. offshore terminals, maritime service platforms) steadily grows, so will the economic and ecological advantages of a multifaceted offshore platform. The diverse principals and designs of hydraulic energy storage plants could easily be integrated into just about any design for such a “multi-use offshore platform”. The diversity of these combination possibilities is one of *Buoyant Energy*’s greatest strengths.

Some of the resulting energy production and energy storage combinations are as follows:

- combination with solar power plants
- combination with offshore wind turbines (”floating wind turbine”)
- combination with ocean current power stations

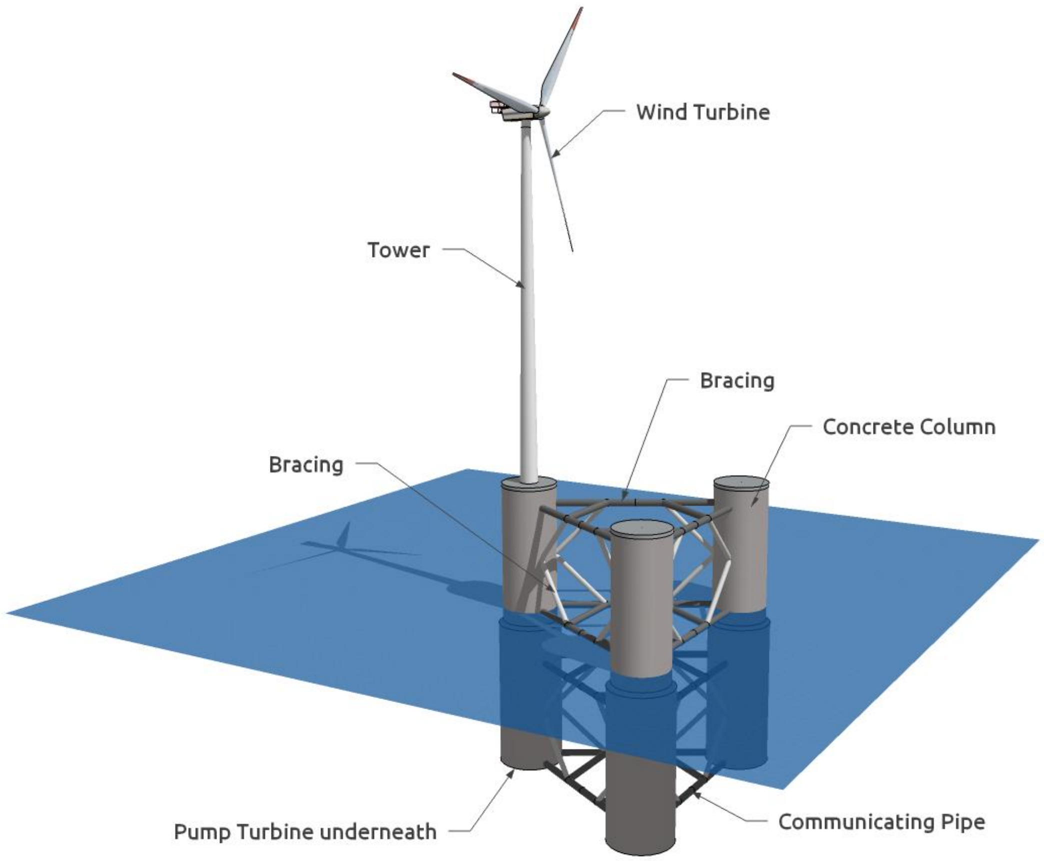

Figure 6: Floating Wind Turbine with Buoyant Energy

The integration of floating energy storage into offshore infrastructure designs is also possible:

- platforms with functional buildings, such as floating hotels or aqua farms
- platforms used as offshore interim storage facilities (e.g. floating container port)

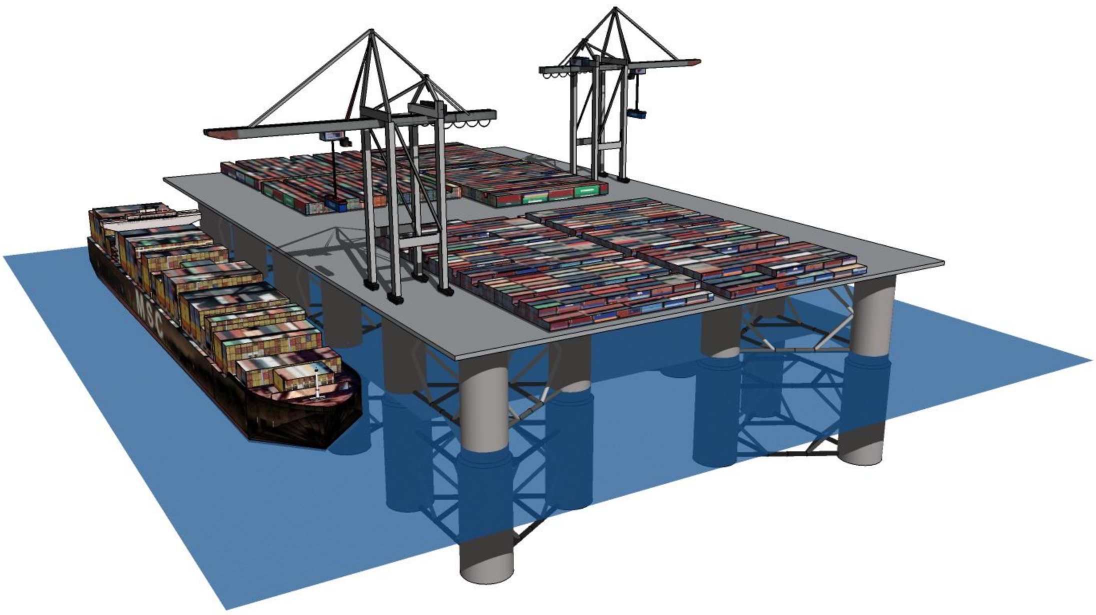

Figure 7: Floating Container Port with Buoyant Energy

Efficiency

For the balance between energy supply and demand to stay as stable as possible, the power loss during the process of energy production, storage and output must be minimal. Due to its architectural simplicity, the energy losses of floating power storage plants are expected to be very small. Apart from the hydraulic losses in the pumps and turbines, only minimal losses are expected at the inlet and outlet. A major advantage lies in the constant pressure head: it allows the pumps and turbines to operate highly efficiently at any given time.

As a result, the overall efficiency of the new *Buoyant Energy* concept will be between 85% and 95%, which exceeds the efficiency of conventional pumped storage plants, which is between 75% and 80%.

Load Cycles / Response Time / Self-Discharge Rate

The number of load cycles is unlimited. No number of load cycles would lead to a loss of storage capacity or efficiency.

The response time is within the range of a few seconds. Due to the simple arrangement of the components, *Buoyant Energy* exceeds even the excellent characteristics of conventional pumped storage plants.

The system’s self-discharge rate depends on the tightness of the valves at the pumps and turbines, but the range in difference is expected to be irrelevantly small.

Storage Capacity / Energy Density

The useable energy content of floating hydraulic energy storage is dependent upon its mass (structure, technical equipment, additional loads) and the size of its cavity (water reservoir). To estimate the energy stored, one must consider an idealized system, wherein the total mass is concentrated in additional loads and the cavity has a cylindrical shape. In this case, the storable energy content is at its best if the cavity is half full with water at maximum immersion depth *h* (see Figure 8).

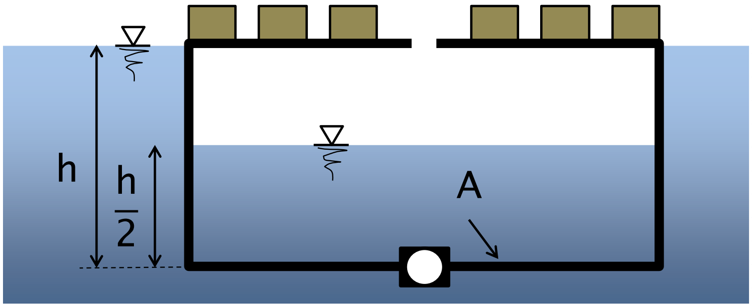

Figure 8: Schematic Diagram of an Idealized System

The energy content or storage capacity *E* of idealized hydraulic energy storage plants is calculated using the following formula wherein the mass of the hydraulic energy storage plant, including all additional loads, is *m*, *g* is the gravitational acceleration, ρ_{Fluid} is the density of water, *h* is the maximum immersion depth and *A* is the base area.

$$E = m \cdot g \cdot \frac{h}{2} = \frac{h}{2} \cdot A \cdot \rho_{Fluid} \cdot g \cdot \frac{h}{2} = A \cdot \rho_{Fluid} \cdot g \cdot \frac{h^2}{4}$$

In such an idealized system the mass *m* of the hydraulic energy storage plant is proportional to its energy content *E*.

$$m = A \cdot \rho_{Fluid} \cdot \frac{h}{2} = \frac{2 \cdot E}{g \cdot h}$$

The following graph illustrates the relationship between the base areas A and the immersion depth h for various energy contents E.

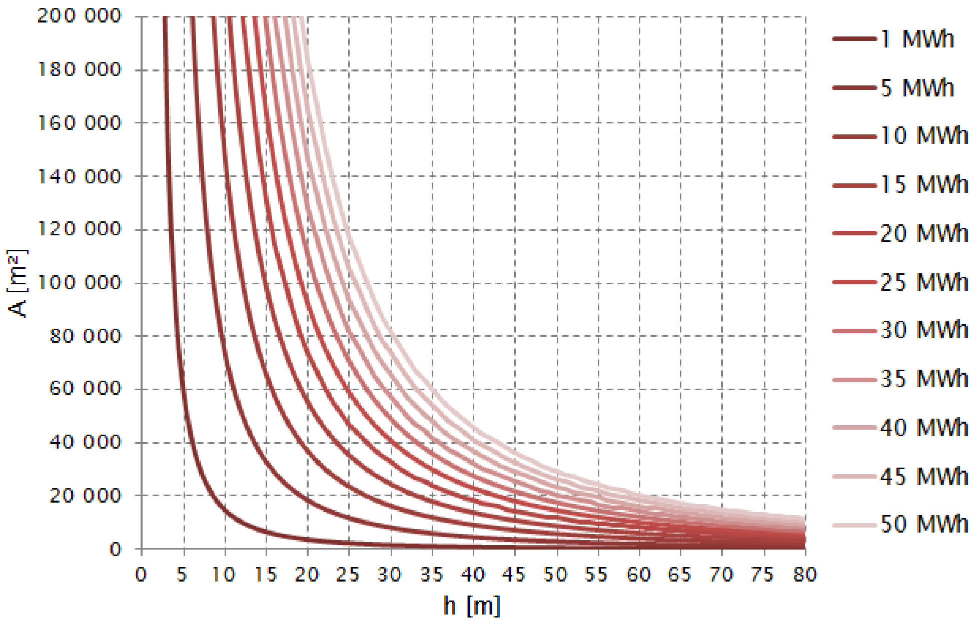

Figure 9: Energy Storage Capacity

The energy density is comparatively low. However, due to the unlimited number of load cycles, the short response time and the high operation efficiency, the advantages are significant when compared to other energy storage concepts.

The gravimetric energy density of an idealized hydraulic energy storage system is:

$$\rho_{grav.} = \frac{E}{m} = g \cdot \frac{h}{2}$$

The volumetric energy density of an idealized hydraulic energy storage system is:

$$\rho_{vol.} = \frac{E}{h \cdot A} = \frac{m \cdot g}{2 \cdot A} = \rho_{Fluid} \cdot g \cdot \frac{h}{4}$$

Rated Power

The installed power of the pump and turbine assembly is arbitrary, determined only by the intended field of application. Standard pumps function using a predefined power capacity. At their optimum operating point the power consumption and water flow are constant. Standard turbines, however, can be adjusted to the required power by regulating the water flow. When the pumps and turbines are simultaneously active a portion of the water is circulated, in what is known as a hydraulic short circuit, thus creating an infinitely variable energy output or consumption possibility at any time, while still operating at optimum efficiency. Furthermore, changing the operating status of pump to turbine mode and vice versa can be done very quickly, which is also a trait unique to *Buoyant Energy's* power storage system.

AREAS OF APPLICATION

Decentralized floating hydraulic storage systems can store and release energy generated from any source on demand. *Buoyant Energy* is characterized by its fast response time, high efficiency and scalable rated power. On top of that it is fully dispatchable and can be scheduled to generate electricity when required. Because of these wide ranging characteristics any number of areas of application would benefit from *Buoyant Energy*. The following sub-chapters will go into detail on some of the most important possible areas of application.

System Balancing

Buoyant Energy offers the potential to dynamically transfer renewable electricity from times and areas of excess supply to times and areas of peaking demand. Electricity generated during off-peak times can be retained and then sold to meet peak demands. This can help address fluctuations in supply from renewable sources, which can occur within seconds, minutes, hours or days. A fast-responding, fully dispatchable and highly efficient storage system is exactly what the energy supply system needs. That is what *Buoyant Energy* is. It doesn't even burn fuel and has a minuscule carbon footprint.

Ancillary Services

Due to its fast response time and fully dispatchable energy generation, *Buoyant Energy* can serve the Ancillary Services markets perfectly with frequency and voltage regulation.

Regulation is a service purchased by grid operators; it is used to manipulate the frequency of the grid, which in turn ensures the stability of power systems. The higher the percentage of the overall energy that comes from fluctuating renewable energy sources, the higher the need for regulation services.

Off-Grid Energy Solutions

On natural and artificial islands and in remote rural areas with no link to the energy grid, electrical power supply from renewable energies is a commercially viable alternative to conventional diesel generators, but finding a way to stabilize their system is especially challenging. The development of a stable energy supply system based on renewable energy sources has become a necessity. Now, with the help of *Buoyant* Energy, the technology for such developments is available. With a mixture of wind and solar energy, supplemented by the *Buoyant Energy* storage system, off-grid energy supply systems will be able to generate their own energy in a CO_2-free manner.

OUTLOOK

Due to subsidized feed-in tariffs in the European Union, like the “Renewable Energies Law” in Germany, the portion of renewable energies in the overall power supply system has grown considerably in recent years. At the same time, there is no financial incentive for renewable energy power plants to be built, that supply electricity demand-oriented (purchase commitments, fixed rates). This is leading to increasing problems in the power supply system. A growing portion of wind and solar power strongly depends on the development of suitable storage technologies, so that the power supply system can become more climate-friendly and above all, reliable.

The present European policies (EEG[3], etc.) are not providing sufficient incentives for such technology innovation. In the course of the amendment of Germanys “Renewable Energies Law” (EEG, 2011) some approaches to change the situation were discussed. The implementation of suitable policies for the integration of storage technologies into the market within the European Union can therefore be expected in the near future.

Economic Feasibility

The economic feasibility of energy storage systems strongly depends on the political decisions that will be made in the near future. The strength and ideal compatibility of one or many combination possibilities play a decisive role in the result of an economic analysis.

Alternative energy storage concepts, like the pumped storage plants in Central Europe, often require increased transmission capacities which, in turn, demand a costly expansion of the transmission and distribution network. The decentralized use of floating hydraulic energy storage devices directly at the site of energy production or consumption could prevent a large proportion of said network expansion costs, while the transmission losses would be minimized. Coastal cities, offshore wind energy or photovoltaic parks are ideal locations for buoyant hydraulic energy storage systems, because they would prevent excess costs and minimize transmission losses.

[3] EEG – German Renewable Energy Act

Research

We are currently working on a macro-economic analysis and evaluation of hydraulic energy storage devices based on the *Buoyant Energy* principle. Another main focus of ours is the identification of possible designs, construction methods, materials and system components that could maximize efficiency. Above all, the combination of small floating energy storage units with wind turbines and their arrangement in clusters is a promising approach with many advantages that we are researching.

Research partners and licensees are welcome: Please contact us!

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