Development of Hydraulic Energy Storage Systems for Decentralized Applications

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Introduction

Energy storage is not a new concept in itself. It has been an integral component of electricity generation, transmission and distribution systems for decades. But now the power landscape is changing dramatically with the move to "fuel-free" power. The shift to renewable sources, mainly in the form of wind and solar power, is sustainable, but at the same time subject to natural fluctuations. Wind does not always blow and the sun does not always shine. Therefore, stable and reliable power supply is a bigger challenge than ever before. It has to regulate now both fluctuating electricity demand, as well as fluctuating power supply. Decentralized energy storage is becoming a key component of the future grid in order to balance energy supply and demand. The University of Innsbruck is working on two innovative concepts for hydraulic energy storages that are suitable for decentralized use onshore and offshore.

1. Background

During the age of industrialization conventional and nuclear power plants supplied energy for the growing cities and factories. The sites of energy production and demand were concentrated in urban structures and the network connected them with some large power lines.

The power landscape with renewable energies is more complex and follows favorable natural conditions in its site selection, such as strong wind load zones for wind farms. This leads to a decentralized structure of energy production and thus changes the whole energy supply system. The power grid must now follow this process, which takes time and money. In addition, wind and solar power, which make up the majority of renewable energy resources, are subject to natural fluctuations. Distributed storage units, which are placed near the energy production, could compensate for the fluctuations and also help to reduce the necessary network expansion.

2. Two Ideas of Hydraulic Energy Storage Systems

Pumped storage stations are currently the most effective energy storage systems. However, their principle requires a mountainous region to store electricity in the form of potential energy. Wind farms in contrast, are preferably built in high wind load zones, which are situated mostly in plains and offshore. For this reason, large transmission networks are necessary with the increasing risk of transmission losses and high investment costs.

In order to meet the energy storage needs of the future, a mix of effective storage technologies for various demands is required. The Unit of Hydraulic Engineering at the University of Innsbruck is currently working on the development of two different types of hydraulic energy storage systems, called *Powertower* and *Buoyant Energy*, which can make an important contribution to balance electricity supply and demand onshore and offshore. Their technology is based on the well-established principle of pump storage plants but developed for decentralized applications. With the use of a pump turbine, energy is stored by lifting a heavy load to a higher energy level. For energy regeneration, the load is lowered under gravity and drives a turbine.

Both systems have a variety of advantages. Their construction is simple and robust with environmentally friendly components. As the storage medium they use only water. The storage capacity can be expanded modularly and they work with a high efficiency of about 80%. The operating costs are very low for a very long lifetime. The number of load cycles is unlimited and the short run-up time ensures the immediate availability of the system. In the following they are described in detail.

3. Powertower

3.1 Concept

The energy storage system *Powertower* consists of a water-filled shaft, in which a cylindrical load is lifted up by a pump in order to store energy. To release the energy, the direction of flow is reversed. The load drops under the influence of gravity and drives a turbine, which feeds the generated electricity into the grid. The arrangement of the pump turbine is possible inside the load (like in fig.1) or outside the shaft. For construction with an integrated pump turbine the hydraulic losses are reduced and only one shaft has to be drilled. The external solution brings on the other hand a better access to the pump turbine for maintenance. The hydraulic machine components can be combined in one pump turbine or be installed in two separated machine units.

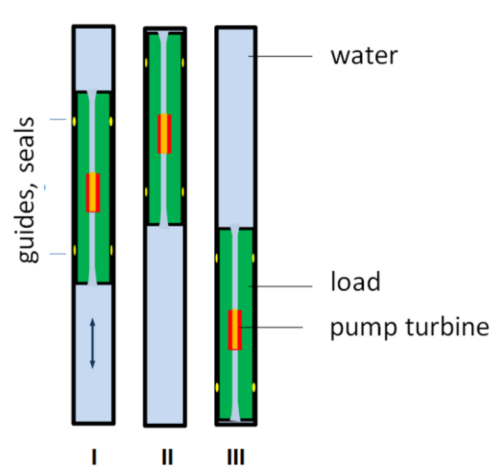

Fig. 1: Principle sketch of a Powertower (I: charging state, II: charged, III: discharged)

The complete system is independent of the topography and can be constructed next to renewable energy generation or industry, also in flat regions, underground and offshore. In this way transfer losses in the grid can be reduced.

For different requirements the energy content of a Power Tower can be adapted by scaling the shaft (volume of the storage reservoir) and the load (water head). Single Power Towers can be built as well as clusters of combined Power Towers (see fig. 2).

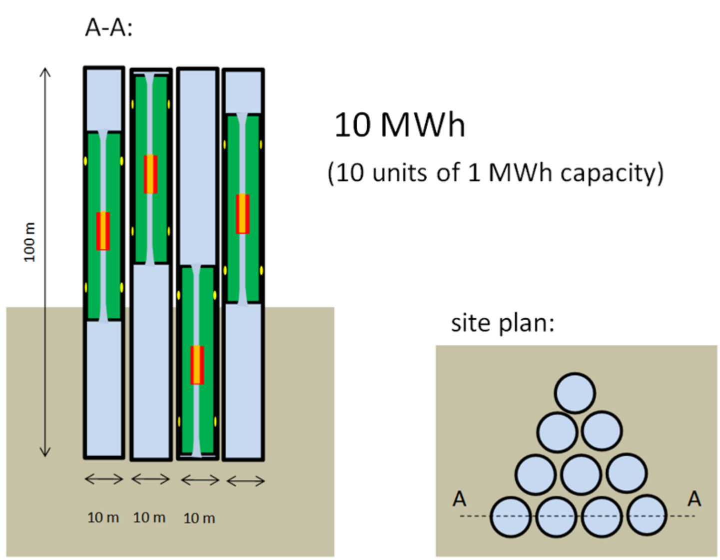

Fig. 2: Cluster of Powertowers with a storage capacity of 10MWh

A cluster of Powertowers can be controlled via the switch on and off of single units. The cluster should be assembled from modular parts and would then be, if necessary, further expandable.

Many sizes and configurations of Powertowers are conceivable. The system can be scaled according to the requirements. In comparison to other storage technologies the investment costs of Powertowers are relatively high for a relatively low energy density. Cost-effective construction methods for standardized Powertower sizes would help to reduce the investment costs. Once a Powertower is built, it is a sturdy system with a long service life and low maintenance costs.

3.2 Research Project

Since 2008 the University of Innsbruck has been involved in preliminary investigations on this concept. In 2011 a research project funded by the Austrian Research Promotion Agency was launched. Its objectives are the proof of functional capability, optimization of the components in experimental studies, development of feasible concepts and profitability analyses.

Within the project two model tests of Powertowers were built and tested in the hydraulic lab at the University of Innsbruck. The first model test PT 1 was realised with an external pump and a steel load of one metric ton (see fig. 3). For this configuration a second smaller recirculation pipe is needed. The hydraulic losses of the system components are determined with pressure measurements in several points. PT 1 proved the functionality of the concept for the first time.

Further experiments are planned with additional springs. Spring systems increase the pressure in the lower reservoir path-dependent and thus increase the energy density of the system.

Fig. 3: Model test PT1 with an external pump turbine

For the next step a model test with an integrated pump turbine was planned and constructed. The PT 2 consists of a 6 m tall pipe with a diameter of 2.40 m. This is placed vertically on a foundation at the outside area of the lab (construction process see fig. 4). The load is a piston composed of heavy concrete rings, which together weigh 40 tons. To use the maximum possible capacity the load is 3 m high, the half-height of the tower. Inside the piston a steel pipe is installed which contains a submersible pump. It can be run reversed and so also be used as a turbine. In the small sector of pump storage stations up to 100 MW the cost benefit is better for pumps working as turbines than for designed pump turbines.

Because of the limited budget of the project, the components for the model test were taken from different fields, as standardized products and adapted and combined in the workshop of the hydraulic lab. Finally the model was finished and the heavy load can now be moved up and down smoothly by the small pump with an electrical power of 7.5 kW.

The model test can also be run by an external pump turbine situated in an added recirculation pipe. In this way the various configurations can be compared with respect to their efficiencies.

When the load is lifted up, a butterfly valve, which is positioned above the pump turbine, can be closed so that charged state is obtained. For energy release, the butterfly valve is opened and the turbine is switched on.

Installed measurement systems show the position of the load and the pressure head at several locations during operation. The rotation of the pump is regulated by a frequency converter and a power meter displays the resulting electrical power. Thus, the velocity of the rising or sinking load can be controlled.

Fig. 4: Construction of model test PT2 with an internal pump turbine

3.3 Outlook

After investigations of the operation behavior and optimizations of the components it is planned to go on with the development of the Powertower step by step. For the next phase the university is looking for cooperation with companies specialized in construction, mechanical engineering and energy supply to get new funding.

The followed stage plan shows the next steps:

	PT 2 (constructed)	PT 3	PT 4
shaft H (m) / D (m)	6 m / 2.3 m	30 m / 6 m	100 m / 10 m
load (t) /pressure head (m WS)	42 t / 8.7 m WS	1100 t / 29 m WS	15300 t / 145 m WS
height of the load (m)	3 m	10 m	50 m
performance (kW)	~ 4 KW	~ 125 kW / 0.6 m^3/s	~ 1000 kW
capacity (kWh)	0,2 kWh	~ 30 kWh	~ 1000 kWh

4. Buoyant Energy

4.1 Concept

Buoyant Energy is an energy storage concept for offshore applications. It uses a smaller reservoir (buoyant platform), that is situated within a larger reservoir. Water can be moved from one reservoir to the other by means of pumps and turbines (see fig. 5).

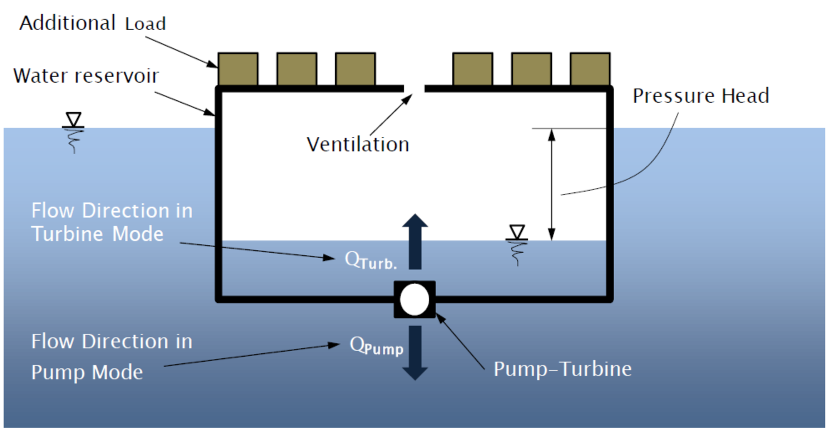

Fig. 5: Principle of Buoyant Energy

The energy is stored solely through the potential energy of the mass of the floating structure. In order to store energy, water from the smaller reservoir is pumped to the larger reservoir. 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. During the store operation the pressure head remains constant. Thus the pump turbine can be optimally designed.

The large reservoir could be any large body of water, like a lake or an ocean. The unique concept of Buoyant Energy enables, for example, the placement of floating storage structures in the vicinity of offshore wind farms (see fig. 6).

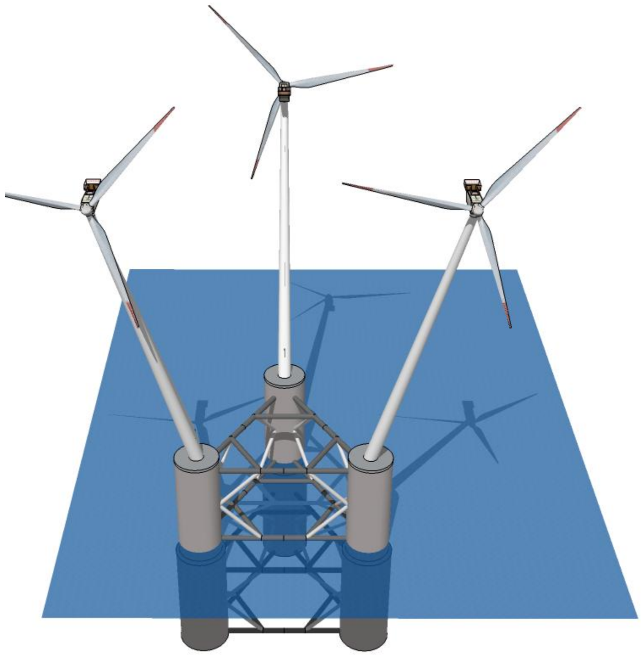

Fig. 6: Floating Wind turbine combined with Buoyant Energy

Moreover, the principals of Buoyant Energy can easily be integrated into many designs of multi-use offshore platforms. As the demand for offshore energy, aquaculture and transport infrastructure, e.g. off-shore terminals, maritime service platforms, steadily grows so will the economic and ecological advantages of a multifaceted offshore platform. Buoyant Energy uses the well-known pumped storage technology and adapts it to a new environment and new fields of application.

4.2 Outlook

To investigate the concept of the Energy Storage system, experimental studies are necessary. In cooperation with experts and engineers for floating platforms and pump turbines in sea water, the University of Innsbruck wants to develop and test prototypes of the new concept. Challenges also include the mooring system and the floating stability, which should be guaranteed even in high waves.

5. Summary

The hydraulic energy storage systems *Powertower* and *Buoyant Energy* represent two new options to solve the challenges of the energy market in the future. The technologies are feasible; their investment costs can be reduced by standardization of the components.

Whether you can earn money these days with the construction of new pumped storage concepts also depends very much on the future political framework. Additional energy storage is needed! But the provision of energy storage is so far paid insufficient - also for conventional pumped storage plants nowadays. This must be changed! Then also new concepts will have a vital chance on the market.

The Authors

V. Neisch studied Civil Engineering at the Technical University of Berlin, focusing on hydraulic and geotechnical engineering. She wrote her thesis on a measurement method for the control of dam safety by means of a fiber-optic temperature measurement at the Technical University of Munich. There she worked in the hydraulic lab at several physical model tests in the fields of hydropower and river engineering. Since 2011 she works at the University of Innsbruck; at present as a project assistant on the development of hydraulic energy storages and she is managing the hydraulic lab.

R. Klar studied Civil Engineering with focus on Hydraulic Engineering and Tunnel Construction at the University of Innsbruck. Then he worked four years at Schönherr Consulting Engineers in the field of hydraulic engineering, flood protection and ski-slope design. This was followed by two years' experience at INTALES GmbH Engineering Solutions specializing in the application of nonlinear analyses for complex lightweight structures and software development for the aerospace industry. In the year 2009 he joined the team of Prof. Aufleger at the Unit of Hydraulic Engineering as Research Associate and PhD Candidate.

M.Aufleger studied Civil Engineering at the Technical University of Munich. Subsequently he worked there as research assistant at the Institute of Hydraulic and Water Resources Engineering, obtained a doctor's degree in 1996 and his postdoctoral lecture qualification in 2000. Furthermore he worked as Manager of the Laboratory of Hydraulic and Water Resources Engineering in Obernach. Since 2007 he is full professor for Hydraulic Engineering at the University of Innsbruck. He conducted many projects in the field of dam safety, river engineering, hydraulic and sediment transport modeling, hydropower etc.; he is member of numerous committees.