Pumped storage – How small can you go?

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How small can you go?

Distributed energy storage in buildings is expected to play an increasing role in the future energy transition. As pumped hydro is by far the most successful storage technology, Guilherme Silva asks does this prompt the question: could pumped storage be used on a much smaller scale in buildings?

Figure 1: Upper reservoir of the Goudemand residence pumped storage hydro (in 2015).

Representing such an important share of energy use, it is no surprise that buildings are one of the first elements to tackle for fighting climate change and the dependence on fossil fuels. Inside buildings, appliances are becoming more efficient, mostly due to strong energy use standards, while the buildings themselves enjoy new design processes that further optimise their behaviour. Construction technology is also keeping up, with new materials and techniques that embrace the transition while renewable energy sources, such as solar panels for water heating or electricity production through photovoltaics, are even allowing for buildings that produce more energy than what they use on an annual average.

The problem with most renewables is that their generation is variable in nature. One solution to solve that variability is to use energy storage, effectively decoupling the required timely match between energy generation and use. With buildings representing such an important share of energy use and with most renewable energy sources being of a distributed nature, distributed energy storage in buildings is expected to play an increasing role in the future energy transition.

Among the different energy storage technologies, pumped storage hydro is by far the most successful technology, representing most of the installed storage capacity worldwide, although for large installations. This prompts the question on whether such technology could be used on a much smaller scale, namely in buildings, given its simplicity and possible synergies with the existing water infrastructure. The physics, however, are demanding: the limited floor loads and height of the buildings would lead to low energy density which means low energy storage capacity. The economics also seem challenging: large installations are competitive since, with minimum civil works, a large storage capacity can be obtained from a geographically suitable site. In a building, however, everything would have to be built and economies of scale would not be present for such small installations. Therefore, it seems intuitive that making pumped storage competitive on a small scale, especially in buildings, would be challenging but the question still stands on how small can one go. How small is it still feasible?

Figure 2: Lower reservoir and Pelton turbine of the Goudemand residence pumped storage hydro (in 2015).

Pumped proposals

A few authors have proposed pumped hydro energy storage for buildings. Fonseca and Schlueter [2] proposed such a system for an informal community of 3000 people, occupying an abandoned complex of five unfinished buildings in Caracas. They imagined distributed water tanks, due to load floor limits, through different floors coupled to the building's water infrastructure. With a storage capacity of 85kWh, the system was more expensive than using lead-acid batteries but the authors defended that externalities such as water security of supply and technological simplicity rendered it the best choice.

Stoppato et al [3] also proposed a small-scale pumped hydro storage, although not in a building, coupled to a cogeneration system, batteries, and PV in order to supply electricity, heat, and water to a resort of 170 people in Italy. Despite the optimistic input values, optimisation resulted in two 175m^3 artificial concrete reservoirs, placed at a height difference of 50m, for a storage capacity of 24kWh. Using a reversible 7kW pump, the pumped storage project would increase the lifetime of the 148kWh lead-acid battery by reducing the discharge rate and depth-of-discharge. Again, externalities such as technology simplicity and greenhouse gas emissions mitigation were presented as important externalities, especially for a resort.

Manolakos et al [4] described an existing pumped storage hydro scheme for a remote village of 13 homes in a Greek island, coupled to 18kW photovoltaics and a 100Ah lead-acid battery. The project consists of two 150m^3 water tanks, at a height difference of 100m, with a 40kWh storage capacity. A multistage centrifugal pump is used for pumping while another is reversed and used as a turbine. A variable-frequency drive adjusts the pump rotation speed according to the available excess power. No references are made to the economics of the project but the system, with an estimated efficiency of about 30%, is also used for irrigation and household water supply, with the easy maintenance being a crucial advantage.

Innovative pumped storage at Negundo innovation centre

In Froyennes, Belgium, an innovative pumped hydro storage system is being built in the Negundo innovation centre [5]. The installation uses an existing 1500m^3 artificial basin for rainwater collection as the upper reservoir (figure 3) and an underground 625m^3 lower reservoir (figure 4) with the available head ranging from 6 to 10m. Both are connected by a 70m long, 30cm diameter underground polyethylene pipe featuring a 10.5kW Ensival-Moret single-stage, centrifugal pump fit with a variable frequency driver (figure 5) allowing a hydraulic efficiency of 83% in pump mode and 73% in turbine mode. The installation sits well in the Negundo innovation centre as a demonstrator not only for integrated pumped hydro but also for an exemplary building complex already fit with solar panels, wind turbines, and batteries. The installation was also designed as a test rig for hydraulic equipment, a place where manufacturers can bring their own equipment and test it under a variety of conditions.

Looking back at the project which started in 2014, Alessandro Morabito, one of the engineers behind the project, points out the civil works and the design of the hydraulic machine as the biggest challenges: "Picking a reversible machine that can work efficiently with a variable head for such small capacities is no easy task and the engineering people did a great job in fitting the lower reservoir among the existing buildings". Meanwhile, the place is mostly ready, just waiting for the reservoirs to fill up with rainwater. Then it is just a matter of getting everything to work together, says Alessandro, one headache at a time.

Enter the Goudemand residence

The Goudemand residence is an apartment building complex located in Arras, France where, in 2012, part of the common areas were rendered grid-independent using solar panels, wind turbines, batteries, and an integrated pumped storage project [1]. To the author's knowledge, it is the first existing installation of its kind. It is part of a larger renovation where the electricity use in the common areas (except for the lift) was also reduced by about 80%, through the replacement of intercoms for more efficient models and lighting for more efficient LED models coupled to presence and light sensors. Electricity generation is provided by a 2.2kW photovoltaic installation and two 500W vertical-axis wind turbines which, meanwhile, have been deactivated and replaced by different models. The pumped hydro makes

Figure 3: Upper reservoir of the Froyennes project (in 2017).

Left – **Figure 4: Underground lower reservoir of the Froyennes pumped hydro storage (in 2017).**

Above – **Figure 5: Reversible hydraulic machine of the Froyennes project (in 2017).**

use of the 30m height of the building to store water in the 200m^2 roof reservoir, up to 60m^3 at a depth of 30cm (figure 1). It was built by waterproofing the roof and existing surrounding walls with the contractor estimating that such configuration brought an additional cost of €700 to a typical roof waterproofing of €10000. The reservoir is only fully emptied for the annual clean of accumulated plastic bags and dead birds, increasing the lifetime of the waterproofing and avoiding trespassers on the wind turbines.

The lower reservoir is located in the basement, consisting of five rectangular 10m^3 plastic water tanks (figure 2) connected to the upper part by a 450W Pelton turbine and an 18W electrovalve while pumping is ensured by a 1.5kW multistage pump. The 3.5kWh useful energy capacity of the project is small compared to the 24kWh of the lead-acid battery, but proves essential in extending the battery's lifetime of about 1000 cycles. The system is set to provide local energy generation to the common areas of the residence, with the remaining recharging the battery, and finally the pumped hydro storage. When the local energy generation is not sufficient to supply the common areas, the battery starts discharging down to a certain depth-of-discharge until the pumped hydro kicks in, feeding the local load and recharging the battery [1].

The economics of the project are not publically available but the contractor estimates the entire renovation at about €150,000. Nevertheless, contractors and equipment suppliers indicated lower average cost estimates of €38,000 for the pumped hydro, €35,000 for the remaining energy production and storage equipment, and €27,000 for the energy efficiency measures [1].

Getting the numbers right

A pumped storage project requires six basic components: two reservoirs, a pump, a turbine, piping, and a control system. For the reservoirs, a waterproofed structure can be used for low cost, as seen in the Goudemand residence. Otherwise, a plastic water tank can be used with an average cost of €300/m^3 for a vertical cylindrical plastic tank, plus installation. For the hydraulic machinery, the bigger the better in terms of efficiency and economies of scale. Efficiency ranges from 50-60% and cost from €2-4/W for a centrifugal pump with a head of 5-20m and a hydraulic power capacity of 0.5-1.0kW. An electronically-controlled pump could, under the same conditions, raise the efficiency to 60-70% but, with a cost of €4-6/W, the increased efficiency does not prove a good trade-off. On the other hand, small turbines are difficult to come by. The typical solution is to use a pump in reverse, an area where some manufacturers have a large experience but where data is still scarce. Nevertheless, literature suggests that peak efficiency in turbine mode is the same as in pump mode, but for higher head and flow values. Therefore, round trip efficiency would be around 25-35% which is quite low when compared to batteries which boast values closer to 90%. But efficiency itself is only important if the energy input cost is high, since that would also render the energy losses expensive. Piping is about €100/m, while the control system stands for an almost fixed average cost of €7000. Other costs, such as certification, are mostly fixed and can reach up to €3000.

Putting it all together in a 20m height building with a 200m^2 roof surface, one ends up with a €46,000 pumped storage schem with a 2.2kWh electrical energy output. The results look grim knowing that a similar lithium-ion battery installation would cost less than €4000 and have a 90% efficiency, although with a shorter lifetime. The use of an existing lower reservoir, for instance for a building close to a canal, would lower the cost close to €19,000 which is still far from competitive. Further synergies, namely with the existing water infrastructure of the building, are difficult to justify given the very different dimensioning requirements and the strict potable water norms. Therefore, despite being technically feasible, pumped storage is too expensive for small-scale installations, namely in buildings, since it misses on the synergies and economies of scale that render large installations competitive. Also, while other storage technologies are quickly getting cheaper, the maturity of pumped storage hydro contradicts any strong future improvements which, coupled with its low energy density, seems to make it a losing contender for energy storage in buildings. ■

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References

[1] G. Silva and P. Hendrick. Pumped hydro energy storage in buildings. Applied energy 179 (2016) 1242-1250.

[2] J. Fonseca and A. Schlueter. A novel approach for decentralized energy supply and energy storage of tall buildings in Latin America based on renewable energy sources: Case study - Informal vertical community Torre David, Caracas - Venezuela. Energy 53 (2013) 93-115.

[3] A. Stoppato et al. A model for the optimal design and management of a cogeneration system with energy storage. Energy and buildings 124 (2016) 241-247.

[4] D. Manolakos et al. A stand-alone photovoltaic power system for remote villages using pumped water energy storage. Energy 29 (2004) 57-69.

[5] A. Morabito et al. Set-up of a pump as turbine use in micro-pumped hydro energy storage: a case of study in Froyennes Belgium. Journal of Physics: Conf. Series 813 (2017) 012033.