Pelena Energy
Technical Data Sheet

Pumped Storage for Hydro Systems

This Pelena Energy Technical Data Sheet describes the concept of a pumped storage system as used in hydro-electrical systems, often called Pumped Storage Hydroelectricity (PSH). A worked example is provided which aims primarily to demonstrate the losses in such a system.

What is Pumped Storage?

Pumped storage is an energy storage system.

Energy is put into the system by running a pump to move water up a hill from a low-level storage to a high-level storage.

Typically, electrical energy is used to run the pump motor. This electrical energy is converted into gravitational potential energy in the form of water stored at high elevation.

Energy is recovered from the system by running the water back down the hill and through a hydroelectric turbine to convert the gravitational potential energy back into electricity.

The Concept

The Figures below detail the concept of a pumped-storage system. Note the direction of water flow between the Upper and Lower storages in relation to the direction of electrical flow.

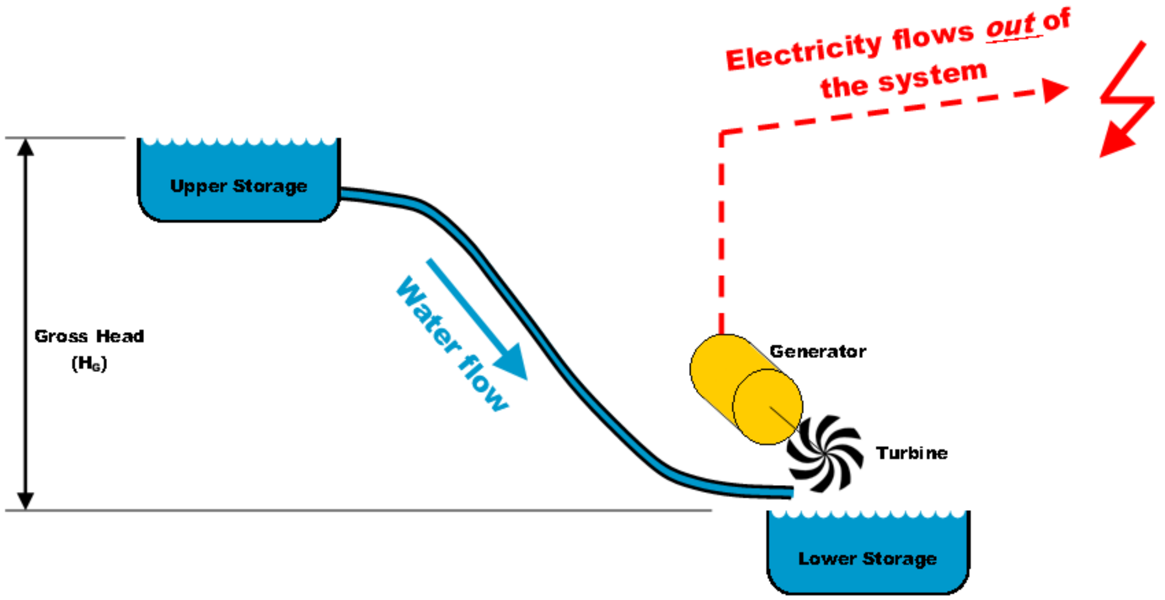

Figure 1: A Pumped Storage system being discharged. Water is flowing *down* the hill through a turbine to generate electricity.

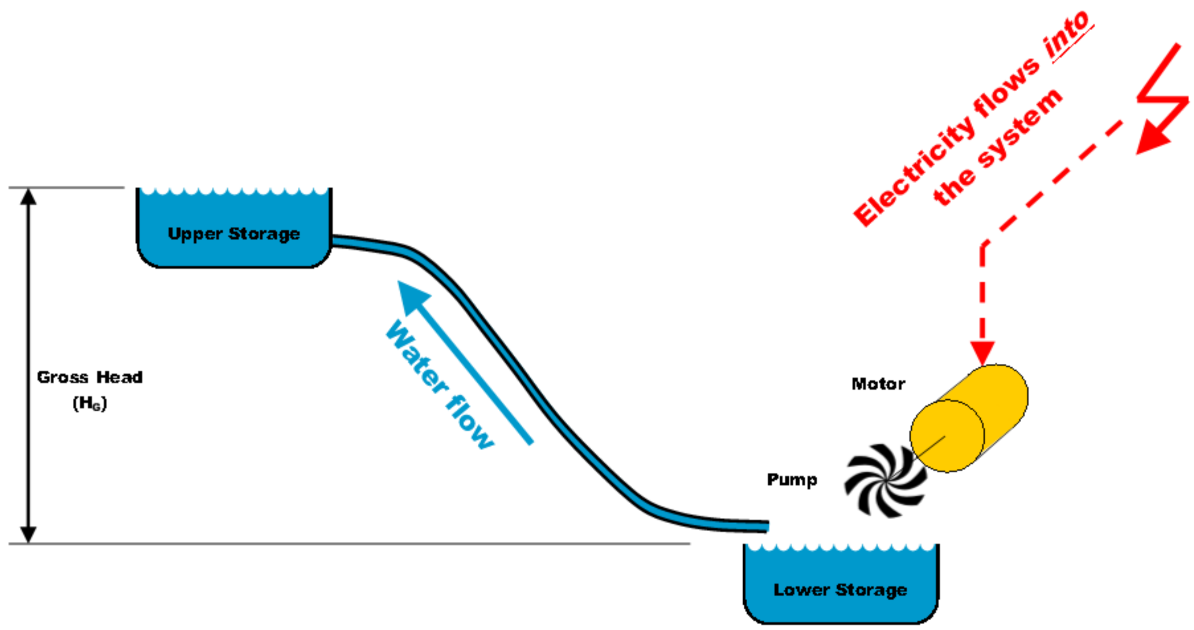

Figure 2 A Pumped Storage system being re-charged. Water is flowing *up* the hill from a motor and pump, consuming electrical power from elsewhere.

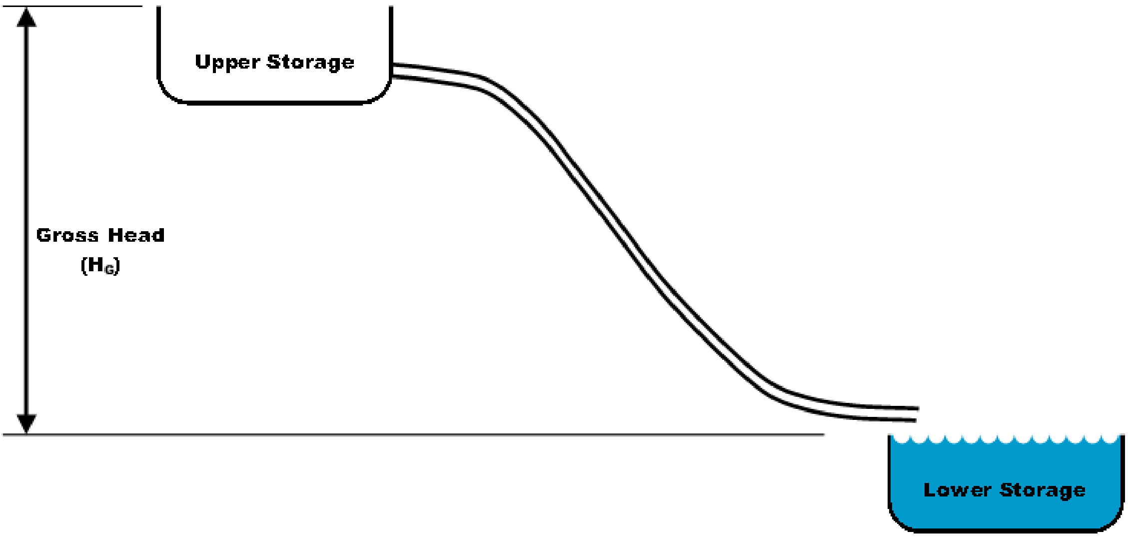

Figure 3: A fully discharged system

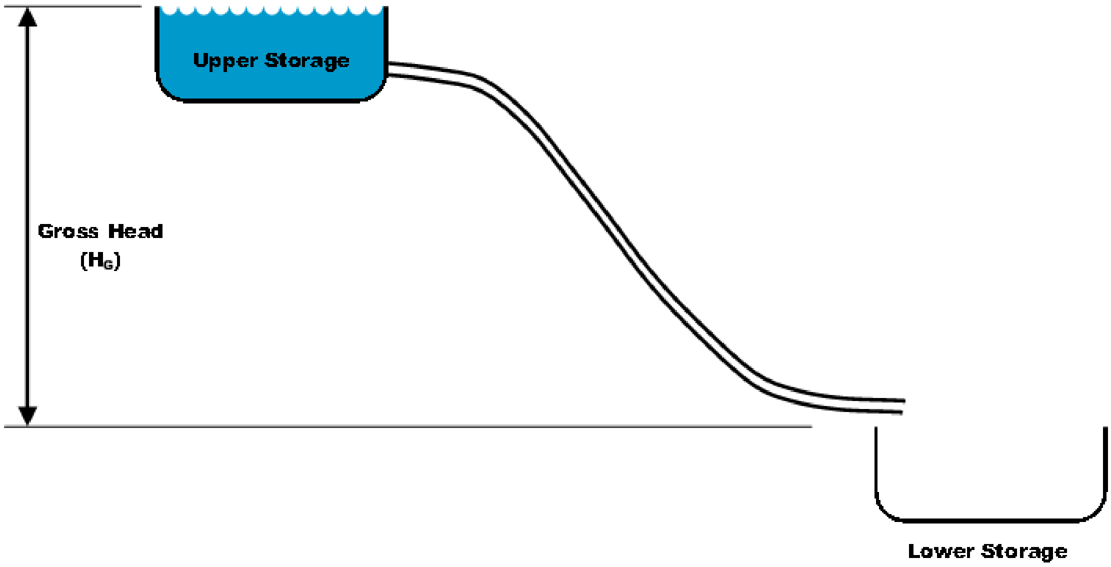

Figure 4: A fully charged system

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Why Pumped Storage?

Pumped Storage is sometimes used to pump water up a hill when the buying price of electricity is very cheap and to later run the water back down the hill to generate electricity to sell at a higher price.

It can also be used to run high-powered loads from a low-power electricity system. In this scenario, a small electricity supply might run for a day to pump water into the high-level storage. This water can later be released through a large hydroelectric turbine over a short period (say an hour or two) to power a large electrical load that is too large for the small electricity supply.

Pumped Storage is commonly used in grid networks where there is a combination of thermal power stations, such as coal-fired power stations, and hydro systems. The amount of electricity being produced and consumed on a grid must be closely matched. The demand on the grid can vary up and down quite rapidly, but thermal power stations can take a long time (sometimes 3 or more hours) to start-up and to stop. Pumped Storage is used to balance out the difference between generation and consumption. When demand is low, the excess generated electricity can be 'dumped' into a Pumped Storage system. When demand rapidly increases, the Pumped Storage hydroelectric generators can begin generating and synchronise to the grid within a couple of minutes to supply the extra demand.

Efficiency

The following example is provided to demonstrate the efficiency of a micro-hydroelectric pumped-storage system. Larger hydro systems typically have greater efficiencies due to typically larger pipelines (with lower water velocities) and more efficient turbines, generators, pumps, and motors.

Example 1:

Given:

- Head (Gross): H_{Gross} = 100 metres
- Pipe Size & Type: PVC pressure pipe, Series 1, 150DN, PN12 (pipe I.D. 142.7mm)
- Penstock length: 350m
- Design Flowrate when used as a hydroelectric system: Q = 40 L/s = 0.04 m^3/s
- Design Flowrate when pumping: Q = 40 L/s = 0.04 m^3/s
- Hydro turbine mechanical efficiency: η_{turb} = 80%
- Mechanical transmission efficiency: η_{Mech} = 95%
- Generator efficiency: η_{Gen} = 85%
- Pump Efficiency: η_{Pump} = 82%
- Motor Efficiency: η_{Motor} = 91%
- Acceleration due to gravity: g = 9.81m/s^2
- Density of water: ρ = 998 kg/m^3

Calculation – when operating as a hydro:

- Pipeline Headloss[1] estimation for this length of pipe with a Flowrate of 40 L/s based on published pipeline data from pipeline manufacturers: 11.2 m
- Therefore the Nett Head (the pressure available at the turbine) is: H_{Nett} = 100m -11.2m = 88.8m
- Therefore expected electrical power[2] produced when operating as a hydro:

$$P_{elec}=H_{Nett}\times Q\times \eta_{Turb}\times \eta_{Mech}\times \eta_{Gen}\times g\times \rho$$

$$P_{elec}=88.8\times 0.04\times 0.8\times 0.95\times 0.85\times 9.81\times 998=22.5\text{kW}_{elec}$$

Calculation – when pumping:

- Pipeline Headloss estimation for this pipe & Flowrate (40 L/s) = 11.2 m
- Therefore pumping Head required: H_{Pump} = 100m + 11.2m = 111.2m (*Note!*)
- Therefore expected electrical power consumed when pumping:

$$P_{elec}=\frac{H_{Pump}\times Q\times g\times \rho}{\eta_{Pump}\times \eta_{Motor}}$$

$$P_{elec}=\frac{111.2\times 0.04\times 9.81\times 998}{0.82\times 0.91}=58.4\text{kW}_{elec}$$

Calculation: Ratio of power of Hydro to power of Pumping:

$$Ratio_{power}=\frac{Power_{Pumping}}{Power_{Hydro}}=\frac{58.4\text{kW}}{22.5\text{kW}}=2.6=260\%$$

Therefore pumping water uphill takes 260% more electricity than is generated when the water runs back down the hill. The reason this occurs is because none of the components of the system is 100% efficient. There are losses (mainly frictional) that make it impossible to get out as much energy as we put in.

To put it another way, if we were to design a system that had separate pumping and generation equipment, so that there were two pipelines that could be run at the same time, we would need 35.9kW_{elec} *extra electrical power* from somewhere outside of our closed-loop pumped storage system in order to keep it running indefinitely.

1 Refer to Pelena Technical Data Sheet 36-R-004 "Penstock sizing" for further details

2 Refer to Pelena Technical Data Sheet 36-R-001 "Assessment of Power for micro-hydro systems" for further information on this calculation.

Note also that due to pipe friction, the Nett Head, or the head pressure at which the turbine operates is only 88.8m, whereas for pumping, the pump must supply a pressure of *at least* 111.2m to overcome the pipe frictional losses (11.2m) as well as the Gross Head (100m). If the pump cannot supply this pressure, water will not reach the upper storage.

If we ignore operational and maintenance costs, this system would generate an income only if the sale price of electricity was more than 260% of the purchase price. This is not unrealistic, as spot prices on electricity markets often have far greater variation than this.

Comment

The above example is for a micro-hydro system of relatively small size. In practice, much larger pumped storage systems are used in large electricity grids, not to make a profit, but to enhance grid stability by matching demand to generation. In these systems, the pumped storage system functions as a "battery" that absorbs some of the fluctuations in demand.

The Perpetual Motion Myth

Of all the energy enquiries Pelena receives, the concept of a "closed loop" hydro is one of the most common. The concept is often stated similar to the following:

> ***"Suppose I was to use the electricity from my hydroelectric system to pump water back up to the top of the hill, then it would flow back down the hill through the turbine & generate electricity which I could then use to power the pump. Therefore, I wouldn't have to wait for rainfall as my hydro would keep going on its own."***

The simple answer to this question is, "Yes, this would work ... *but.....not for long!*"

As can be seen from the example above, more power is needed to pump the water up the hill than what power can be generated by the hydro *at the same Flowrate.* If the pump was reduced in size so that its power demand matched the hydro (22.5kW in the above example), then the flowrate of water uphill would be lower than the flowrate of water downhill. Water could be pumped around the system – until the upper storage ran dry.

The common response to this argument is "But the upper storage will be replenished by the river or stream." This is therefore not a closed loop hydro, as water is entering the system at the upper storage, and must eventually leave it at the lower storage. Water (and energy) are being supplied from the action of the sun lifting the water to the clouds and producing rain at high altitudes.

In conclusion, the fact that a closed looped hydro cannot work is not a conspiracy between scientists, engineers, and oil companies! It is a conflict with the laws of nature!