Numerical Simulation of Long Tailrace Tunnels for Hydropower Pumped Storage Plants

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Motivation

The construction and upgrading of pumped storage hydropower plants (PSHP) will be very beneficial in the years to come in order to regulate the power systems. They are very flexible and allow covering peak demands and storing energy on a large scale.
In this work, the Duge PSHP in Norway is used as a case study. The power plant has two Francis reversible pump-turbines (RPT) with a total installed capacity of 200 MW. In 2017, however, the turbines were refurbished and since then, a lifting problem occurs at the rotor of one of the turbines (Unit 1) when generating at a high load. As a consequence of this problem, the generation has to be restricted to 80% of the maximal load, i.e. 160 MW. The aim of this work is to understand the causes of the lifting and to find a civil engineering solution to this problem by modifying the waterway of the power plant.

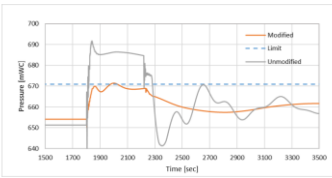
Trash rack in the Duge power plant

Results

In order to solve the lifting problem, three solutions have been selected. The first aims to avoid any problems in the worst load case and to be able to run the power plant at 200 MW again. The second aims to avoid any problems in a normal load case and to run at 200 MW as well. Finally, the third solution aims to be lighter on a technical and economic point of view and to be able to run the power plant at 185 MW. For each solution, the downstream pressure is compared to the unmodified power plant.

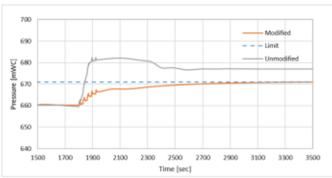
Solution 1

- Addition of a downstream air cushion surge tank
- Addition of a 6 km parallel tunnel in the tailrace



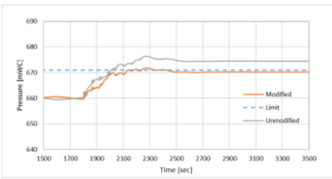
Solution 2

- Increase of volume in the surge tank upper chamber
- Addition of a 6 km parallel tunnel in the tailrace



Solution 3

- Addition of a 6 km parallel tunnel with smaller section in the tailrace

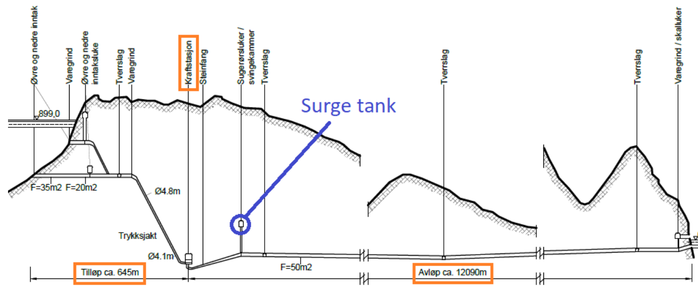


After an economic analysis is made, the final costs for each solution are estimated considering the construction works (new access tunnels, excavation, draining of tailrace tunnel, etc.) and the losses due to the power plant outage. The costs are given in different currencies (1 NOK = 0.1177 CHF and 1 NOK = 0.1008 EUR):

	Solution 1	Solution 2	Solution 3
Norwegian kroner [NOK]	275 million	215 million	162 million
Euros [EUR]	27.7 million	21.7 million	16.3 million
Swiss francs [CHF]	32.3 million	25.3 million	19.0 million

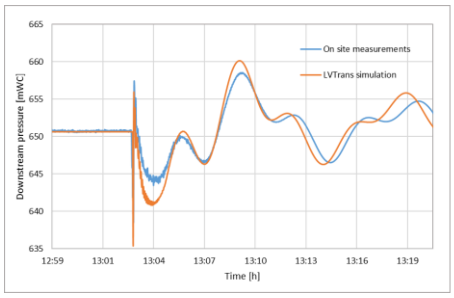
Methods and materials

The Duge PSHP has a very long tailrace tunnel (12 km) in comparison to the headrace tunnel (650 m). The high friction losses due to the long tailrace give a high downstream pressure rise at the RPT units in generating mode.



Duge power plant layout

In order to propose modifications of the power plant, a model is made on LVTrans, a numerical modelling freeware allowing to calculate transients in a loaded pipe system [1]. To simulate the real behaviour of the prototype, the model is calibrated against downstream pressure measurements, done at the draft tube wall for a turbine shutdown.



Calibration of the LVTrans model

The calibration is considered satisfactory, since only the first pressure peaks, which are the worst, are of interest for the lifting problem. The lifting of the rotor (246 tons) at Unit 1 occurs when the resulting vertical force acting on the runner is directed upwards; the downstream pressure is therefore the significant factor to consider.
Norconsult, a Norwegian consulting company, calculated that 1 [mWC] downstream pressure change = 4.1 [tons] of lifting force. This is obtained by multiplying the pressure by the surface of the outlet. Moreover, the maximal lifting force acting on the runner should be no more than 75 tons [2]. Considering this, it is possible to have a threshold that the downstream pressure should not exceed in order to safely run the power plant without the lifting problem.

Discussion

As showed in the results, the modifications of the power plant improve both the steady and unsteady states and allow the downstream pressure at Unit 1 to remain under the critical threshold. However, the solutions seem to be disproportionate, considering the total amount of the required investments and construction works. A limitation of the economic analysis is that only the total costs are considered, but not the associated benefits of having more power available.
Finally, the Duge power plant will receive new runners in the future, which means that the problem may be solved in a few years. Considering all these conclusions, it seems that it is probably better to not opt for a civil engineering solution to solve this lifting problem.

References

[1] **Svingen, B., 2016.** *LVTrans manual*. Sintef & NTNU, Trondheim
[2] **Norconsult, 2014.** *Aksialkrefter - måleresultater og gjennomgang av tiltak*. Sira Kvina Power Company, restricted access