STRUCTURAL ENGINEERING ASPECTS AND DEVELOPMENTS OF PUMPED STORAGE PLANTS

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Abstract: The generation of electricity by means of pumped storage plants has become particularly important due to the changing basic conditions in the energy market as well as the deregulation in the last years. Adjustments of crucial parts of the hydropower plant such as headrace tunnels and penstock pipes etc. in addition to increases of pump and turbine capacities have become necessary for existing plants particularly because of a operational change and have been partly implemented in the meantime.
The experiences with and purpose of such structural changes shall be explained and illustrated by means of specific examples.
The original design basics such as the operational time of pumps or turbines, general energy efficiency conditions of the operation and given regulations in the energy market etc. are virtually not applicable anymore. In addition, the protection of nature and general ecological conditions have affected the structural design and construction of parts of pumped storage plants such as underground and coventional reservoirs and new structural design concepts have partly been implemented or are currently at the planning stage.

1 Basic electricity market conditions

The basic electricity efficiency conditions for the structural design of pumped storage plants have changed considerably since the deregulation of the electricity market which took place about 10 years ago. Until about 1990/2000 the evaluation of capacity, capacity availability and electrical output with regulated, index-linked prices (price/KW, price/KWh for low tariff, high tariff periods etc.) was an essential and important design criterion for pumped storage plants. The available water resources, the specific investment costs of the hydropower plant as well as the specific production costs of the electricitiy versus feasible operational hours under full loads were regarded as additional design basics. In special cases pumped storage plants were also designed as a supplement in the case of operational breakdowns of other large generating units like thermal or atomic power plants. The economic design limits were determined by marginal costs as break-even point and were the base for the capacity limits of pumped storage schemes. The economic benefit mainly applied to regulated tariff differences between low and high tariff periods (seasonal price differences – winter/transitional/summer season and/or day-time/night-time tariffs or weekly/weekend tariffs etc.).

As standard values for the economical and technical design of pumped storage schemes with annual reservoirs, a range between 700 and 1000 full load operational hours was chosen or determined for the capacity of the plants. For the less common weekly pumped storage plants, 15 to 25 full load operational hours were determined as standard design values for the plants' capacity.

Since the year 2000, the increasing electricity demands on one hand and the upcoming trend to alternative energy resources (wind, biomass etc.) on the other hand have considerably influenced the electricity market and the need of peak energy as well as the design criteria of existing and new pumped storage schemes.

With the beginning of extensive international electricity exchanges and power trading in Central Europe, the differences in seasonal or day-time/night-time tariff periods were not decisive for the technical and economical design of pumped storage plants anymore. The electricity market price formation at the stock exchange with base and peak as well as spot prices is now regarded as being crucial instead of the regulated tariff system. In addition, the increased normal network requirement, the additional demand for balancing energy – particularly for wind energy – as well as a plant availability within a short time became increasingly important for the technical design of new plants. Therefore, the rather simple design criteria of the last century have considerably changed and a rather clear technical design and evaluation of new plants have become increasingly inconsistent and difficult due to the rapid changes in the market. Independently from the more difficult basic electricity market conditions for a long-term validated technical design criteria of new pumped storage plants, the changed market has lead to a boom for new schemes and upgradings of existing plants. Because the long-term tariff and benefical basics are currently not predictable in relation to the lifetime and period of amortisation of pumped storage schemes, there are increasingly more challenges for a correct structural design of such plants.

2 Structural design aspects

There are currently tendencies to increase the capacity and performance of existing pumped storage plants. In addition to the mechanical and electrical enlargements, it is also generally necessary to increase the performance and capacity of headrace tunnels or penstock pipes etc., for instance. In most cases, it is increasingly difficult or even impossible to extend existing penstock structures due to their age. New solutions had to be searched for and very often these solutions included new headrace tunnels with powerhouse caverns.

The headrace tunnels of many existing structures which were constructed from the middle of the last century until the 1980s were designed with no or very few reserves due to the not very highly developed construction technologies for tunnels. Thus, the existing headrace tunnels made it nearly impossible to increase the flow capacity or extend the plant. Many current and future projects require a capacity upgrading of the headrace structures to construct new tunnels with powerhouse caverns or new steel-pipe penstocks and powerhouses. In most cases, the existing headrace structure and/or the powerhouses remain in operation and in addition the new plants are operated sperately. The capacity of the upper and lower reservoirs remained unchanged in most cases but the capacity of the existing reservoirs was slightly enlarged in other cases. The existing reservoirs of some pumped storage plants were slightly enlarged. The extension and rehabilitation of hydropower plants in Kaprun, Reißeck and Kops can be seen as current examples in Austria. Similar approaches and modifications are currently also taking place in numerous neighbouring countries.

Due to the increasing demand for adjusted reservoir capacities and peak electricity, there are currently some projects in consideration where an existing hydropower station (e.g. a high head or river run-off power station) can be converted or extended by means of a new storage reservoir to create high-performance pumped storage schemes. To build a new upper reservoir generally includes the option to freely design and also optimize the new structural parts of the plant such as the volume of the upper reservoir or the construction of the headrace tunnels, penstocks etc. Current cases in Austria, for example located in the Danube region, with existing river run-off plants can be used as lower reservoir for a new pumped storage scheme if the mountains located nearby allow for sufficient crosshead and the construction of a new upper reservoir.

In numerous other cases the available storage volume of the existing pumped storage plants has not been sufficient for the new requirements of the energy market since the formerly typical requirement to redistribute water resources (e.g. summer / winter, day-time / night-time, low / high tariff periods) is not applicable at this scale anymore, for instance. The plants are increasingly operated according to the market developments of the electricity or the basics for optimizing the proceeds and the original structural plant designs such as the storage capacity are not realistic anymore.

In addition to other current projects, heightening the upper dam and increasing the reservoir volume of the pumped storage scheme Nassfeld, the Bockhartsee Dam or increasing the lower reservoir at the pumped storage scheme Kops II, Rifa Reservoir, as well as the planned new reservoir Kühtai are examples in Austria. Since the extension and enlargement of lower reservoirs has been particularly difficult in in populated or narrow valleys, the existing lower reservoir at the hydropower plant Nassfeld which was too small for an economical operation under the new conditions has been extended by constructing caverns to increase the capacity of the lower reservoir. This design has been applied in Austria for the first time and thus an additional underground storage volume of approximately 160.000 m³ was created. The structural design included 4 main caverns, 300 m in length, and 3 connecting caverns.

3 Economical design aspects

The technical design of newer pumped storage schemes is currently based on electricity market basics which have undergone considerable changes and is therefore particularly difficult due to the wide market range. From a technical point of view, the relatively clear tariff regulations of the second half of the previous century generally constituted a more distinct base.

Approximately 2200 to 2800 operational hour for turbines and approximately 2800 to 3300 operational hours for pumps can be regarded as currently possible design criteria for the structural and mechanical as well as electrical parts of the plant. This means that the operational hours are doubled or tripled in comparison to older plants. In addition, the discharge etc. can be multiplied in the headrace systems and capacity increases are possible which means that the dimensions of individual parts such as tunnels, penstock pipes etc. are considerably larger. Particularly due to the demand for quickly deployable and adjustable plants with shorter load cycles from turbine to pumping operations, highly sophisticated designs for surge chambers etc. are required and the impacts and peak loads have considerably increased. Whereas older plants generally have load cycles from at least 1 minute to approximately 3 or 4 minutes, modern plants are able to alternate loads in less than 1 minute and even within 30 to 40 seconds in special cases.

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