ESC-NEWS

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Hydropower: Higher Efficiency under Changing Conditions

Hydropower is the most important pillar of the Swiss electricity sector, and its importance is only likely to increase further over the coming decades. Although hydropower is a technically mature technology, it still provides a ripe field for research. At ETH Zurich, a wide variety of themes surrounding future electricity production are being researched.

Energy Science Center

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

In particular, scientists at ETH Zurich are using scale modeling and numerical simulations to explore how changing conditions are affecting electricity production and how plant operations can be further technically optimized.

By Felix Würsten

More than half of Switzerland's entire electricity production is generated from hydropower. It is expected that hydropower will grow in importance in the coming years. Yet the potential of those rivers and streams suitable for power production has been largely exhausted. Still, in the future, pumped storage plants will assume a central role in future energy systems by evening out erratic power production from solar and wind power plants and in that way ensuring grid stability.

Changing Production Conditions

Although hydropower is a technically mature technology, it still represents a fruitful area for research, explains Robert Boes, director of the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at ETH Zurich. For example, the electricity industry is interested to know how climate change will impact power production, especially in areas where a large portion of the watershed is covered with glaciers. Recent calculations by ETH Zurich show that in the future there will be enough water available for electricity generation, but that changing conditions – less precipitation in summer, more precipitation in winter and a yearly runoff maximum that comes earlier in the season – will make adaptations by the power plants necessary.

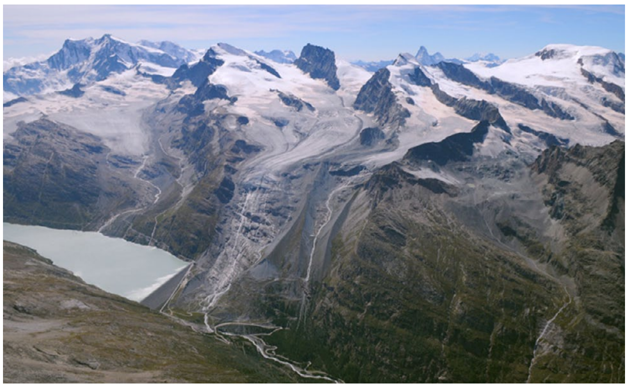
More stringent water protection requirements are also demanding new responses from power plant operators. In recent years, many power plants have built fish passes that enable upstream fish migration. But the issue of how to ease the downstream passage of fish has yet to be resolved, since the fish tend to follow the main current, which does not flow along the fish ladders but through the turbines. An interdisciplinary project that examines both biological and hydraulic engineering aspects should help point the way to developing possible solutions to this problem.

Although most hydropower plants today boast very high efficiency levels, the operators are attempting to optimize the plants still further. "In view of the large amount of electricity generated, small improvements in performance have noticeable economic benefits," asserts Boes. An important phenomenon currently being researched at VAW is the entrainment of air. If the water in the pressure mains contains air, this can lead to serious problems when the water is turbined – from significant reductions in turbine efficiency rates to damages to lugs and water pipes. It has long been recognized that at water intakes in reservoirs vortices can develop from air entrainment. New concepts for pumped storage plants in which pumps and turbines operate simultaneously also pose a challenge for engineers. Here too air entrainment in the pumps must be inhibited as much as possible.

Combining models and simulations

The scientists at VAW study phenomena such as air entrainment partly with the help of physical models in large testing facilities. "For a time it was believed that numerical computer models could someday make physical experiments redundant," explains Boes. "But concrete experience shows that both are needed: computer simulation and lab experiments." There are two reasons why real models are still important: the representation of reality in computer models comes up against certain limits, especially for highly complex flows like water-air and water-sediment mixtures. "Secondly, measurement technology has made great strides, enabling us to study certain phenomena much more exactly than before," says Boes.

Advances in measurement technology are being applied not only in the laboratory but also in field experiments. VAW researchers will soon install a new facility in Oberwallis that will enable the continuous measurement of fine particles in water. Such fine particles pose a serious problem for plant operators, since they contribute to the accelerated wear and tear of the turbine wheels. As with many other VAW projects, the research question here is quite concrete. "Many of our research projects are application-oriented," confirms Boes. "But exciting questions for basic research regularly emerge out of exactly these sorts of projects."



Allalin- and Schwarzberggletscher with Mattmark reservoir (photo G. Kappenberger, 2007)

Impact of climate change on hydropower exploitation in glacierized basins

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The Alpine hydropower industry is particularly concerned by the impacts of climate change. The fact that many basins exploited for hydropower production are partly glacierized and that glacier retreat is one of the most visible effects of climate change itself contributes significantly to these concerns. In the framework of various studies conducted at VAW, a dozen alpine catchments were analyzed with respect to the expected glacio-hydrological changes.

The results show that the expected evolution is strongly basin-specific, with the present glacier volume and its distribution playing a major role. As rule of thumb, basins with present glacierization larger than one third show a characteristic, two-phased evolution in the expected evolution of annual discharge. In a first phase, runoff increases due to enhanced glacier melt, whereas in a second phase, runoff will decrease due to decreasing glacier area. In all analyzed basins the transition between the two phases is expected to occur before 2050. The timing of the transition is associated with the present ice volume.

Total annual runoff is not the only relevant factor for hydropower exploitation. The distribution of annual runoff over the year plays an important role as well. Although climate scenarios indicate only minor changes in total annual precipitation until the end of the century, the distribution over the year is expected to change significantly. On average over the Swiss Alps, a precipitation reduction of 20% is expected for the months July and August, whereas an increase by 10% is anticipated for the winter months. These changes in precipitation, the unevenly distributed increase in temperature (the most pronounced changes are anticipated in summer and winter) and the expected glacier evolution will lead to significant changes in the runoff regime of alpine catchments. In particular, maximal daily discharge will occur earlier in the year, summer discharge will decrease significantly, whereas runoff in spring and autumn will increase.

Summarizing the findings with respect to hydropower exploitation, one can state: sufficient water will be available for hydropower production in the future. However, the available water volume will be distributed differently over the year, which may require operational adaptations. The exact evolution of annual runoff is strongly catchment-dependent.

» www.vaw.ethz.ch/divisions/gz/projects

Measures to facilitate safe downstream fish migration at large Central-European Rivers

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Providing over 56% of the national electricity supply, hydropower plays the most important role in Swiss energy production. Its importance is justified both by the sheer amount of energy that is produced and by the ecological and economic advantages it presents. Not only is hydropower renewable, but it can supply base load through run-of-river power plants as well as peak load and power storage through pumped storage plants. Pumped storage plants are increasing in importance due to the increase in variable wind and solar power production. Nonetheless, hydropower also faces new challenges, especially in connection with evolving water protection legislation.

The revised Water Protection Act that came into effect in January 2011 stipulates that the major human-induced damages to the Swiss river ecosystems must be rectified within the next 20 years. This will pose tremendous challenges for the energy companies and cantons alike.

An important aspect of the process of water body restoration deals with the recreation of the flow continuum. This includes enabling the up- and downstream migration of fish which can be hindered by run-of-river power plants. Currently, especially the downstream migration vital to the preservation of a number of European fish species is being negatively affected.

For this reason, the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) and its partners Verband Aare-Rheinwerke (VAR), Eawag, swisselectric research and the Swiss Federal Office of Energy (SFOE) are conducting research with the aim of developing innovative structural means to provide a working and safe downstream fish migration in large Central-European rivers. The research project aims to contribute to the sustainable and efficient usage of hydropower in Switzerland and Europe.

The topic of fish migration cannot be addressed with purely biological engineering approaches. Both the river-specific fish fauna and the power plant-specific morphological and structural characteristics have to be considered. Hence, the research team is based on a transdisciplinary approach including specialists from the water power industry and researchers specialised in hydraulic structures as well as fish ecology. The broad array of partners also makes it possible to utilize several research methods in one project, in this case physical model tests, prototype tests and active fish migration monitoring.

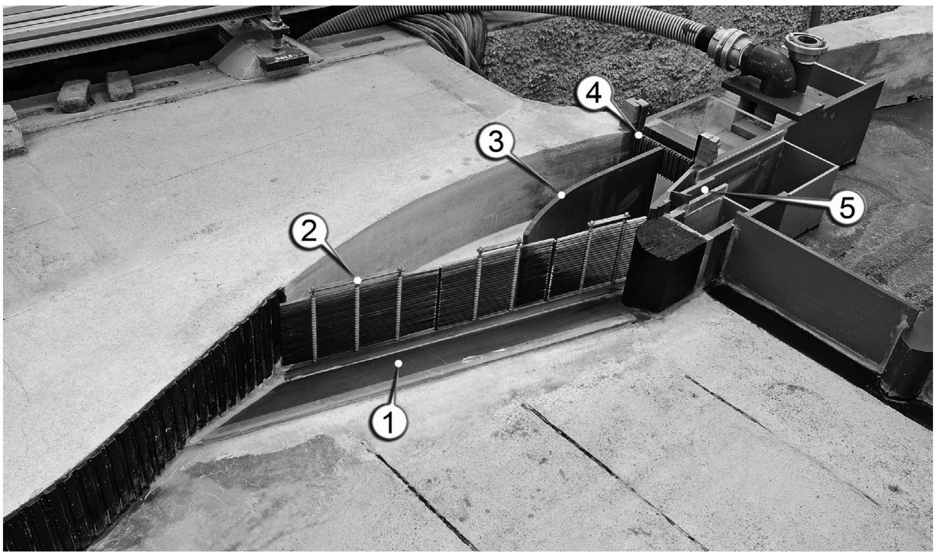

Fig. 1: Physical model of a power plant intake (1) with fish guidance screen (2), guidance wall (3), skimming wall (4) and bypass (5) constructed at the Laboratory of Hydraulics, Hydrology and Glaciology to study ecologically and economically sensible means to realize downstream fish migration

Hongrin-Léman - Hydraulic Investigations of the pump-storage scheme Veytaux 2

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In addition to power production, pump-storage hydropower plants are used for load balancing in the electricity grid that is necessary due to fluctuating power demand over the day. By pumping water from a lower to a higher reservoir, electricity can be stored in the form of potential energy (excess electricity in the grid). In periods of higher demand, the energy is regained by loading the turbines (electricity input to the grid). This type of energy storage is gaining in importance with the increasing use of other renewable, non-controllable energy sources, like solar and wind power.

The pumped-storage hydropower scheme Hongrin-Léman in the Canton of Vaud consists of the Lac de l'Hongrin as the upper and Lake Geneva as the lower reservoir. To increase the power production, the operator Les Forces Motrices Hongrin-Léman SA decided to add a second pump-storage power station. The new station Veytaux 2 is designed with 2 sets of pumps and turbines with a power production of 240 MW, doubling the installed capacity of the plant (one group, 60 MW, of the existing plant will be used as reserve).

The new power station can be operated in the so-called short circuit mode, i.e. the pump and turbine have to run simultaneously. This allows the regulation of the current drain from the network, as pumps cannot be regulated as smoothly and easily as turbines. This operation mode sets special requirements that are being studied in a hydraulic model at VAW:

- Air entrainment: The runner of the Pelton turbines used does not immerge into the tailwater. The water jet impacts on the turbine and is deflected. The impinging of the water droplets onto the water cushion beneath the runner entrains a considerable amount of air into the tailwater.
- Air transport: The entrained air bubbles are transported into the tailwater and slowly de-aerate on the free water surface.
- De-aeration: For simultaneous turbine and pump operation, the water is conveyed directly from the turbine housings to the pump system. For an optimal efficiency of the pumps, the total de-aeration has to be completed before reaching the pumps.

The investigation at VAW simulates the air entrainment at the Pelton turbine. The de-aeration length in the tailwater channel is determined and possible optimizations are developed and tested as to their efficiency.

The hydraulic model at VAW (Fig. 1) is being built at a scale of 1:8.78 and consists of the two turbine housings, the tailwater channels and the pump system. The model is constructed in PVC and acrylic glass and will be commissioned in October 2011.

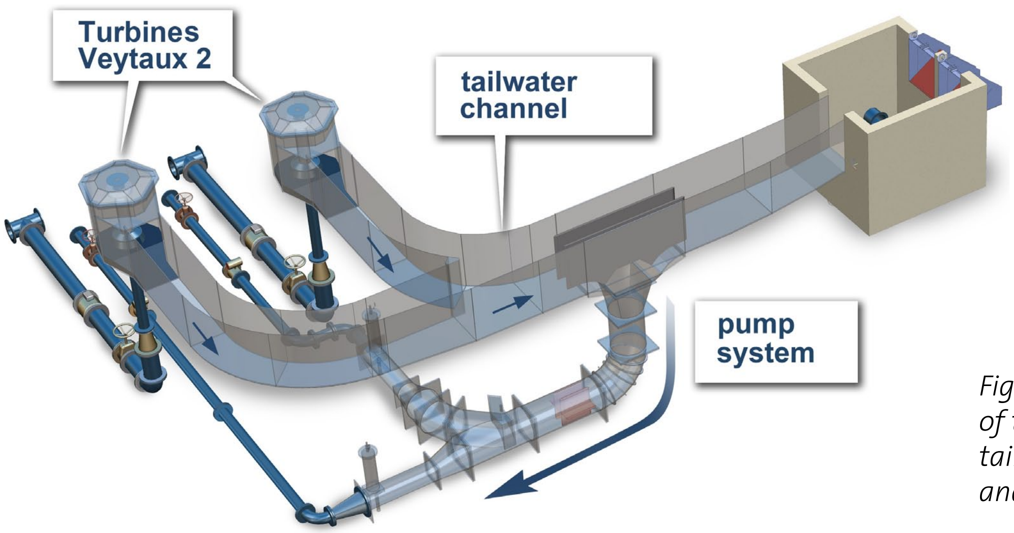

Fig. 1: Physical Model of turbine housings, tailwater channels and pump system

Turbine wear caused by abrasive suspended sediment

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Natural rivers may transport leaves and driftwood, gravel, sand and suspended mineral particles (Fig. 1). Handling the so-called "solid load" is a challenge for hydropower engineers and hydropower plant operators.

Alpine hydropower plants are generally equipped with trash racks as well as gravel and sand traps. At hydropower plants in which water from highly glaciated catchment areas, so-called "glacier milk", is used and the water is not stored in lakes where fine particles could also settle, the turbine water may contain suspended mineral particles of considerable concentration. These may damage the turbines. At a head of 500 m, for example, the jet velocity towards the runner in a Pelton turbine is about 360 km/h. Particularly the hard particles, e.g. quartz, cause wear on turbine parts (Fig. 2). This mechanism is called hydro-abrasive wear.

Nowadays the problem of hydro-abrasive wear is becoming more important as climate change leads to more sediment transport, enhanced efficiency of energy supply is increasingly sought after, and hydropower plants are expected to operate as sustainably and economically as possible. Hence, the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) initiated the research project described here. The project is mainly funded by swisselectric research and the Swiss Federal Office of Energy (SFOE).

In investigating hydro-abrasive wear, a major difficulty to overcome is that suspended load varies strongly both throughout the day and the year, depending on the weather and the evolution of glaciers in the catchment. Thus, continuous monitoring of the concentration and particle size distribution of suspended load is required. Up to now, particle size distribution was only obtained by analyzing bottled samples in a laboratory. In this research project, for the first time in Switzerland a hydropower plant in upper Valais will be instrumented with an in-situ laser diffractometer. This device allows continuous measurement of suspended load concentration and particle size distribution.

The investigation of suspended particles in the headwater of a hydropower plant together with periodic inspection of the turbines and monitoring of their efficiency should contribute to enhancing the understanding and the ability to model hydro-abrasive wear. This can serve as a basis for further improving the layout and design of hydropower plants and their components (e.g. desilting facilities, turbines), their instrumentation and operation.

» **www.vaw.ethz.ch/people/as/felixda/projects/data/pelton_wear**

Fig. 1: Wysswasser creek (left), at the confluence with the Upper Rhone, in Valais, Switzerland: an example of a mountain river transporting bedload and suspended load, coming from a glaciated basin (VAW, August 2010).

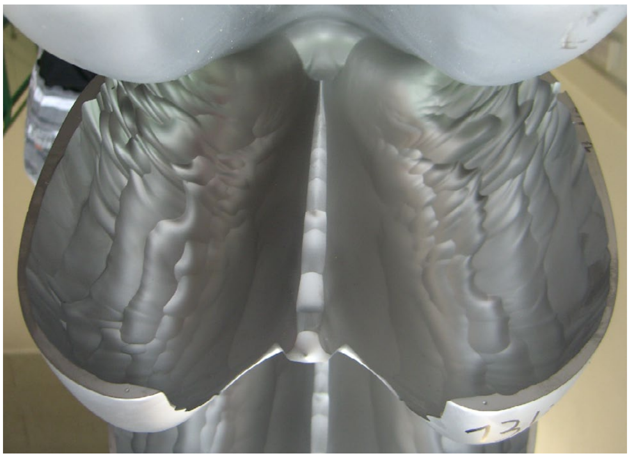

Fig. 2: Example of a Pelton runner, showing heavy damage caused by hydro-abrasive wear. The bucket splitter is no longer sharp and the bucket is "washed out" (TIWAG).

Vortex induced air entrainment rate into pressure systems of hydropower plants

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Air in pressure systems of hydropower plants (HPP) generally has negative consequences such as reductions in turbine efficiency and flow rate as well as pulsations and pressure surges. Vortices at intakes are a major source of air entrainment, requiring significant reserves during planning and operation of hydroelectric power plants to avoid them. Knowing the air entrainment rate and quantifying the resulting potential damages allows the design of counter-measures such as de-aeration systems, thereby improving the efficiency of a hydropower plant, especially with regard to storage management.

Large-scale physical model tests are conducted in a 50 m3 laboratory tank at VAW (Fig. 1), with two pumps providing a maximum discharge of 500 l/s in a closed loop. The vortex formation at the intake is not enforced by certain installation. Thus, the unsteady nature of hydraulic phenomena is undisturbed. The model allows compliance with the generally accepted limits regarding similitude criteria of intake vortex investigations. The horizontal velocity field around the vortex is measured by means of a 2D Particle Image Velocimetry (PIV) on a total area of up to 1 m2. The measured horizontal velocity fields around the vortex, whose rotation affects a wide area, confirm the applicability of the analytic solution of the 2D Navier-Stokes equation for the potential vortex. The resulting air entrainment rate is much higher than expected, however. The device for quantifying the air entrainment is currently being optimized to increase the measurement accuracy at low air entrainment rates. A forthcoming challenge is a complete de-aeration, i.e. a prerequisite to measurements with large air entrainment rates.

The aim of this project is to close the knowledge gap concerning the understanding of vortex-induced air entrainment and thus to improve the practical design of intake structures at hydropower plants. The project is planned to be finished by the end of 2012.

» **www.vaw.ethz.ch/people/wb/moellege/projects/data/wb_Vortex_air_entrainment_dissertation**

Fig. 1: Physical model with tank (black) and a horizontal outlet pipe (plexiglass, d = 0.4 m).

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