Pushing the envelope: Switzerland's approach to unlocking hidden hydropower potential

Andres Müller
EPFL Laboratory for Hydraulic Machines
Avenue de Cour 33 Bis
1007 Lausanne
Switzerland

Cécile Münch-Alligné
HES-SO University of Applied Sciences
Route du Rawyl 47
1950 Sion
Switzerland

Christophe Nicolet
Power Vision Engineering Sàrl
Chemin des Champs-Courbes 1
1024 Ecublens
Switzerland

Vincent Denis
Mhylab mini-hydraulics laboratory
Chemin du Bois Jolens 6
1354 Montcherand
Switzerland

François Avellan
EPFL Laboratory for Hydraulic Machines
Avenue de Cour 33 Bis
1007 Lausanne
Switzerland

Hydropower has consistently played a major role in energy policies around the globe for the past century, due to its outstanding capability of reliably and flexibly supplying clean electricity. Along with that, enormous capacities of other renewable energy sources have been added to the electricity mix over the past decades, such as solar or wind power. Their inherently intermittent nature however makes their large-scale integration into the electric power system (EPS) very challenging, and hydropower is taking again centre stage for guaranteeing the stability of the grid by providing it with the necessary flexibility. This is a crucial condition for enabling the further increase of the clean energy share and, thus, for reaching the ambitious climate goals set by the international community. Grid flexibility and energy storage are key words in this discussion and the contribution from hydropower has to be optimized and maximized. Yet, the potential for conventional hydro is largely used up in industrialized countries like Switzerland, prompting the search for hidden hydro potential by focusing on applications of a different scale and/or different type. This article provides a summary of recent Swiss initiatives in that area, aiming at the increase of both the installed capacity and the operational flexibility of the power plants. New projects include classic small hydropower schemes built onto existing infrastructure, and the development of novel technologies, such as kinetic turbines in tailrace channels or counter-rotational microturbines for the drinking water network. Furthermore, the profitability of small hydropower plants is improved by demonstrating how targeted auxiliary services can be provided to the grid. The generation from the existing hydropower fleet is optimized by developing advanced tools for performance analysis as well as decision making in case of upgrades and by assessing the consequences of off-design and transient operation. Finally, the achieved respectively expected progress through large research projects in the frame of the FP7 and H2020 programs funded by the European Union are summarized. The collaborative nature of these project may indicate a way to how the main energy challenges lying ahead can be dealt with jointly.

1. Background

In the framework of the Swiss Energy Strategy 2050 defined by the Federal Council, the scenario for hydropower foresees an increase of its actual electricity production from 36.4 TWh to 38.6 TWh during the next thirty years; 50% of this additional potential should come from small hydropower. To reach this target, hidden hydro potential must be developed and several actions undertaken with a priority on the harvesting of existing infrastructure to minimize related ecological impacts. This means, among others, that new small hydropower plants in drinking and wastewater networks or artificial channels are to be installed, requiring sometimes the development of new turbines, and that the operating range of small and large hydropower plants must be extended. Furthermore, as a particularity of the Swiss case, many of the existing power stations will see their concessions being expired over the next few decades, as illustrated in Fig. 1. In the next 30 years alone, 70% of the entire hydropower fleet, generating a total of 23 TWh annually, is concerned. A renewal will entail a broad modernization of the generating units, necessitating the development of robust decision-making tools to choose the optimal solution among many, by taking into consideration the entirety of relevant technical, economic and ecological parameters.

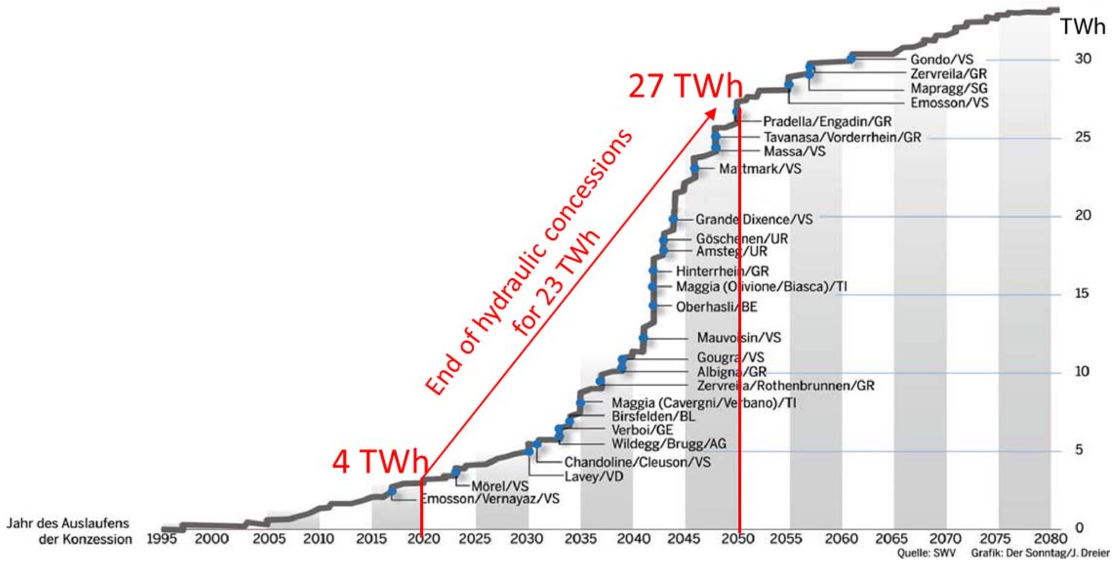

Fig. 1. End of hydraulic concessions in Switzerland until 2080 (cumulative curve of annual production vs. year of expiration). Adapted from ASAE 2012 [1]

The following sections describe a selection of efforts and research projects in Switzerland performed to uncover hidden hydro potential. Chapter 2 is focused on the increase of the installed small hydropower capacity, including new “conventional” storage, run-of-the-river (RoR) and “small” pumped storage (PSP) power plants, as well as the extension of the operating range of existing plants for the provision of ancillary services to the power grid, and finally the development of new turbine types for the drinking water supply networks and existing open-channel structures. Chapter 3 provides insights into best practises for the refurbishment and upgrade of existing hydropower plants across all types and scales, as well as for the diagnosis of structural loads caused by the increase of the number of start/stops in hydropower plants.

2. Development of the small hydro potential

2.1 New small hydro projects

For almost 30 years, Switzerland has been supporting the development of energy recovery in existing or planned infrastructure thanks to small hydro power plants. Based on the observation that any process implying ad water flow and an excess pressure is a potential source of energy, miscellaneous programs and actions were implemented to develop the untapped potential coming from the drinking water, wastewater and irrigation networks, as well from ecological flow released at the foot of a dam, fish pass system, navigation locks and dams, cooling system. All these projects have in common that the electricity generation is not their primary priority, but the second one. This implies the integration of the power plant in the existing infrastructure while guaranteeing its primary function. For this reason, such power plants are called multipurpose schemes. They have many advantages regarding the environmental impact, the production cost and the grid flexibility:

1. Low levelized cost of energy (LCOE). The infrastructure being built and maintained anyway, the capital expenditure is low, as it corresponds only to the additional cost for the generating equipment. The exploitation costs are also reduced, as O&M staff is already hired for the primary function of the scheme.

2. Neutral or positive environmental impact, as the water is already used for another purpose than electricity generation. Moreover, recovering energy from a cooling system reduces the impact of the pumping activity by recovering a part of the spent energy.
3. Local production that can be used by the infrastructure itself or injected on the local electric distribution grid, unloading the transport grid.
4. Electricity production following the human activity (drinking and wastewater energy recovery) and then the electricity consumption.
5. More stable and predictable production compared to the other decentralized renewable energies.

The development of that kind of projects requires a specific know-how, as well for the design of the scheme and the integration of the production equipment, as for the design of fully adapted turbines. Since 1997, Mhylab and HES-SO are involved in such projects, mainly in drinking, irrigation and wastewater energy recovery, these three fields representing most of the Swiss potential. Some examples among many projects that were realized are briefly presented hereafter. Among recent projects put into operation in Switzerland is the one of SITSE in Fig. 2 and Fig. 3, releasing treated wastewater into Lake Geneva. This project is using the difference in levels between the wastewater treatment plant and the lake, running a 110 kW Pelton unit producing around 700,000 kWh a year.

Fig. 2. 3-nozzle Pelton turbine of SITSE

Fig. 3: Carnot dissipator by-pass

Another wastewater turbine is the one from Le Châble / Profray shown in Fig. 4, using the wastewater coming from the Verbier ski resort. With a head of 430 m and a discharge of 100 l/s, this 380 kW unit generates 800,000 kWh per year. Generating in irrigation networks has also been realized, as for instance at the Armary small hydropower plant, shown in Fig. 5, with an output of 105 kW and yearly production is around 450,000 kWh.

Fig. 4. 2-nozzle Pelton turbine of Le Châble

Fig. 5. Armary powerplant

A recent drinking water power plant is located in Ollon-Bruet. The Pelton unit is connected to a 12 km water adduction, under a head of 683 m. With a capacity of 700 kW, this power plant will generate around 2.8 GWh / year. Finally, the reserved flow turbining of Le Day, has been put in operation in 2017. Working under a variable head due to the dam water level variation, the turbine is using a variable speed generator. The 126 kW single regulated Kaplan unit recovers around 1,0 GWh per year.

Fig. 6. Ollon-Bruet Pelton unit

Fig. 7. Le Day small hydropower plant

In 2018 Switzerland had over 270 units installed in existing infrastructures for a yearly production of 146.3 GWh.

2.2 Small scale pump-storage

Pumped storage hydropower plants (PSPs) are currently the only available solution for large scale energy storage with a worldwide installed capacity of greater than 100 GW. The possibility to use small PSPs, with a capacity between around 500 kW and 10 MW, to provide local voltage control and line congestion management to medium-voltage active distribution networks is under consideration in Switzerland. The goal of the project, led by HES SO Valais in collaboration with Mhylab, was to show through existing potential sites the competitiveness of small pumped storage hydropower plants compared to other storage options in case of existing reservoirs. Ten sites have been studied and four of them are under consideration for a first demonstrator in Valais.

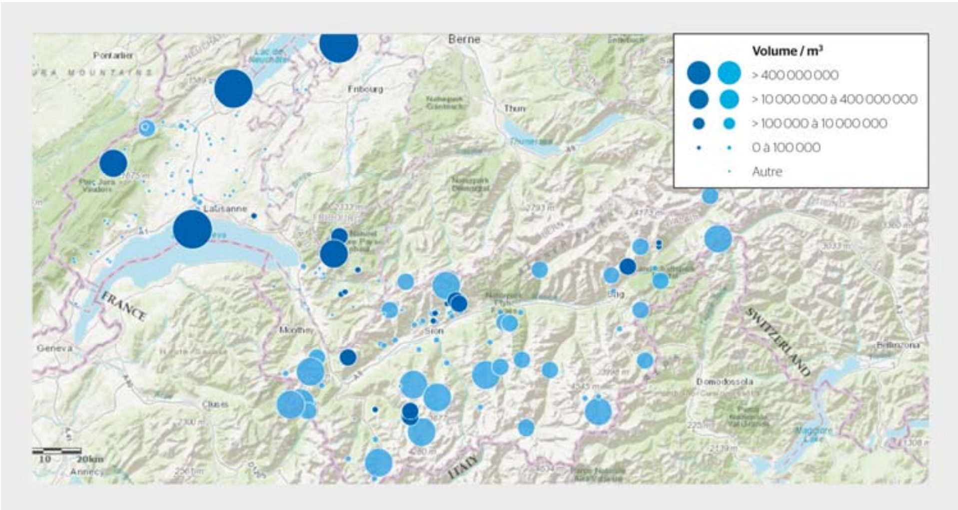

Fig. 8. PSP case studies in Switzerland from [5].

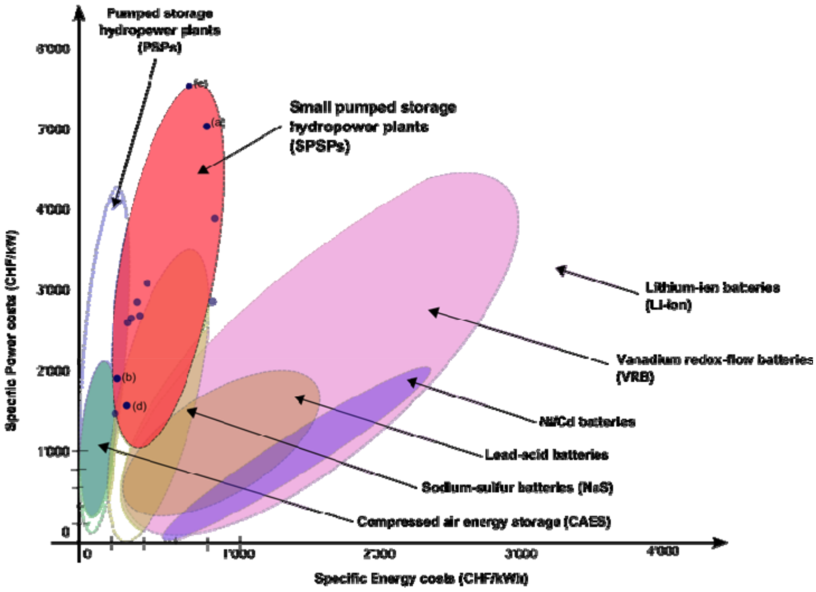

Fig. 9. Comparison of the specific costs for several energy storage solutions.

To compare the estimated cost with the other technologies, Fig. 9 shows the relation between the specific power costs over the specific energy costs for several technologies. Small pumped storage hydropower plants can provide an interesting solution complementary to existing ones. Globally, the investment cost related to the installed power for each site falls in the expected range, i.e. less than 10 CHF per Watt.

2.3 The Small Flex project: enabling the flexible operation of small hydropower plants

Changes in the national feed-in-tariff (FIT) system challenge small hydropower plant owners by introducing the necessity to produce according to the energy demand, thus opening up new business cases. The aim of this project, led by HES-SO Valais and performed in collaboration with EPFL, WSL, EAWAG, PVE and FMV, is to show how small-hydropower plants (SHP) can provide winter peak energy and ancillary services, whilst remaining eco-compatible. The outcome of recent researches of the project partners are applied to a pilot facility provided by FMV with the goal of providing operational flexibility to the SHP owner and therefore harvest additional revenues. The addition of flexibility is done by testing infrastructure and equipment or operational adaptation measures, while assessing their impact in terms of outflows, electricity output and revenues. The lessons learned from this demonstrator will be publicly presented and used as a benchmark for the SHP sector.

The demonstrator site selected is the new small hydropower plant of Gletsch-Oberwald (KWGO) owned by FMV and equipped with two Pelton turbines of 7MW each, with a mean gross capacity lower than 5 MW and an electricity production focusing on the summer period.

Fig. 10. Gletsch-Oberwald hydropower plant

Storage capacities have been identified, a first volume being the settling basin and the forebay tank while the second one is part of the headrace tunnel. During the building of the power plant, two gates have been integrated connecting the settling basin and the forebay tank to allow the use of the first identified volume, representing almost 4'000 m^3, during the low discharge period, from fall to spring. During the first experimental campaign of the project, lasting three weeks, several production peaks have been generated from 15min to two hours and from 1.5 MW to 6.5 MW with different recovery intervals. The two first weeks were dedicated to the hydropeaking events monitoring in the alluvial area and the last one to follow the energy demand and thus the spot price. An increase of the electricity produced by up to 40% has been observed by operating the power plant with production peak at high power with a higher efficiency [6]. An increase in the outcome is expected as well. The analysis of the results is still on-going. The tailrace water level variations and their ecological impact are also being evaluated. A second campaign is planned in the beginning of 2020, with this time the objective to use part of the headrace tunnel in order to double the storage capacity.

2.4 The DuoTurbo project: counter-rotative micro turbines for the drinking water networks

To tap the available potential of the drinking water network, a new turbine type has been developed. In the framework of the DuoTurbo project, HES-SO Valais and the EPFL Laboratory for Hydraulic Machines, in collaboration with the industrial partners Telsa SA, Jacquier-Luisier SA and Valelectric Farner SA, have jointly developed a new micro-hydroelectric system for drinking water networks with a target power of 5 kW – 25 kW. The core of this new energy recovery station is a counter rotating microturbine. The modular in-line "plug & play" technology requires low capital expenditure, targeting profitable operation after 5 to 10 years. Furthermore, harvesting energy from existing drinking water facilities has no environmental impact.

One stage of the DuoTurbo microturbine consists of two axial counter-rotating runners. Each runner is featured with a wet permanent magnet rim generator with independent speed regulation. This compact design enables a serial installation to cover a wide range of hydraulic power [7]. In this project, an innovative design for the hydraulic, mechanical and electrical components of the turbine have been developed using numerical and experimental approaches [8]. Several prototypes were built and tested on a dedicated hydraulic test rig at the HES-SO Valais.

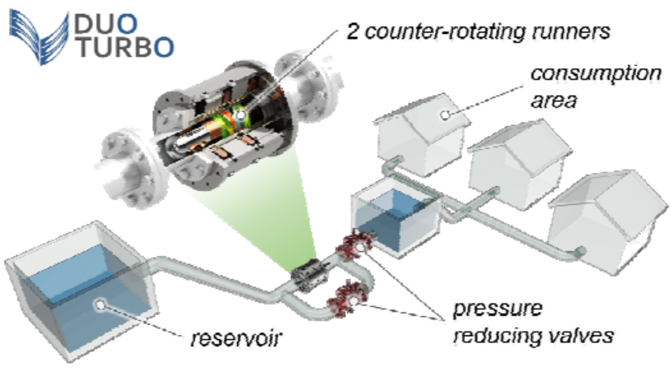

Fig. 11. Illustration of the DuoTurbo concept.

Finally, a first product DuoTurbo of 5 kW has been successfully tested and commissioned on a pilot site in May, 2019, to assess the long-term behaviour of the system (see Fig. 12). The monitoring of the first 12 weeks of operation shows a satisfying behaviour in terms of stability, operating regulation, efficiency and vibration. No significant drifts of the efficiency or vibration levels have been observed. Before the end of 2019, a second pilot site will be equipped. Further investigations are ongoing in urban drinking water distribution networks [9].

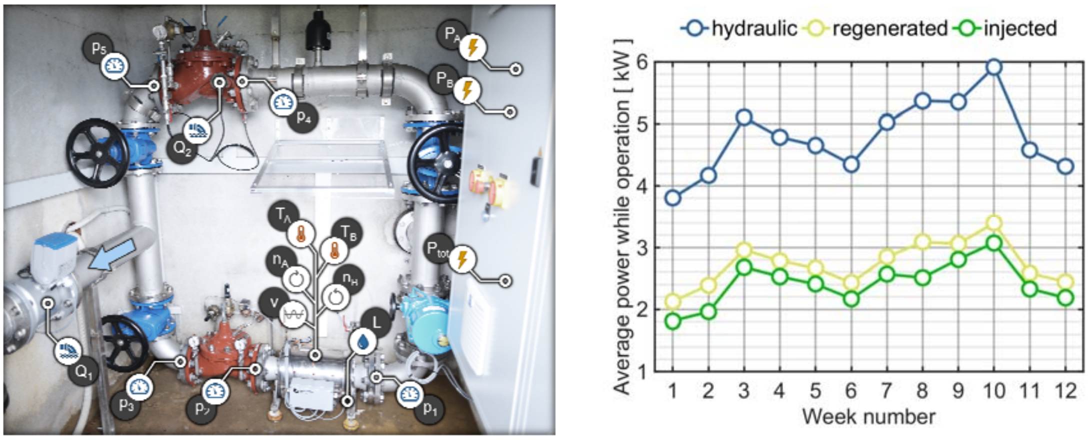

Fig. 12. Savièse pilot site for DuoTurbo: installation and first weeks of power monitoring.

2.5 Kinetic turbine: harvesting the energy of open channel flows

To tap the renewable potential of ocean and river streams, so called kinetic turbines have appeared several decades ago. A new prototype of such a turbine was developed by HES-SO Valais and Stahleinbau GmbH, and installed on a pilot site. The hydraulic concept of the turbine is characterized by a horizontal rotational shaft and a Venturi duct. This duct is composed of four parts respectively: a straight inlet section, a convergent part, a straight part for the runner and an outlet diffuser. The final geometry of the duct has an inlet diameter of 1.128 m and an outlet diameter of 1.60 m, its total length being of more than 4 m, as illustrated in Fig. 13.

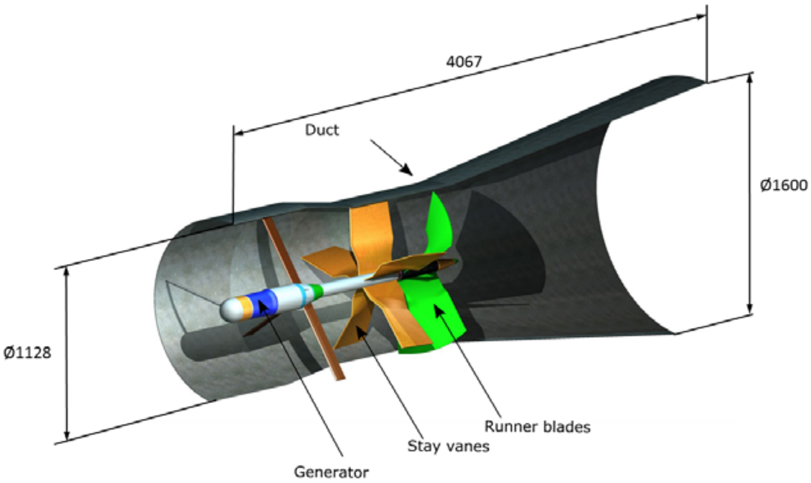

Fig. 13. Sketch of the kinetic turbine prototype along with main characteristic dimensions in mm [10].

The pilot site to assess the performance of the first prototype is the tailrace channel of the run-of-the-river Lavey Hydropower plant in Switzerland; see the schematic view in Fig. 14. The Lavey power plant installed on the Rhône River produces each year 400’000 GWh with an installed capacity of 90 MW (three Kaplan turbines). The tailrace channel is 650 m long with a maximal width of 43.5 m and a maximal depth of 7 m.

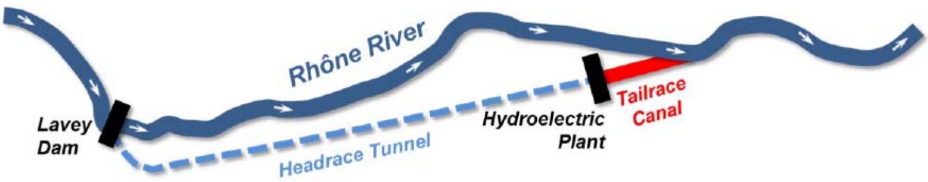

Fig. 14. Geographical situation of the Lavey hydropower plant on the Rhône river.

The performances of the turbine were measured for several flow conditions, changing the discharge and the turbine depth for several pitch angles of the machine. These measurement campaigns confirmed the expected performance obtained numerically by CFD and the measured power coefficient reached was higher than 80%. After the performance assessment of the turbine prototype, the possibility of installing a hydrokinetic turbine farm on this pilot site was investigated using numerical simulations, as illustrated in Fig. 15.

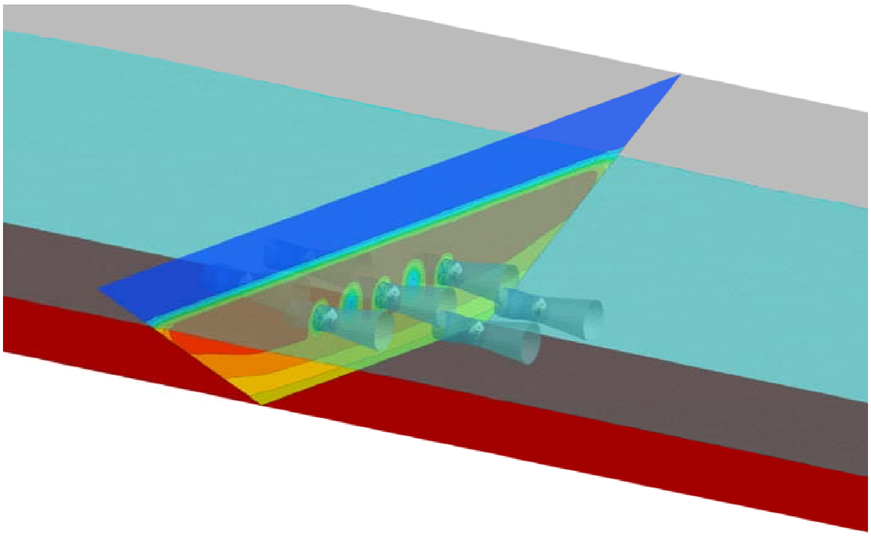

Fig. 15. Unsteady numerical simulations of a hydrokinetic turbine farm in the Lavey HPP tailrace channel.

3. Renovation and optimization of the existing hydropower fleet

3.1 The RENOVHydro project: selection of the optimal refurbishment option

Environmental concerns restrict the perspectives of developing new large hydropower plant schemes. An optimal exploitation of the potential from the already existing facilities is therefore crucial to achieve the objectives of the national Energy Strategy 2050. As mentioned above, a large amount of hydraulic concessions will end in the coming years (see Fig. 1). The main stakeholders of each of them will have to estimate the true potential of a refurbished installation before applying for a new concession and long-term investments. Currently, the potential indicated by the Swiss Federal Office of Energy (SFOE) derives from local estimates by the states (Cantons). These estimates are performed separately for each field of engineering and it is therefore difficult to have a global vision of the necessary costs for the renovation of a hydraulic power plant. Moreover, the many combinations resulting from several possible choices in each engineering field leads to a large number of scenarios from which to estimate the potential. This cannot be achieved manually and the scenarios to evaluate must currently be selected a priori.

EPFL has developed an advanced numerical simulation tool entitled SIMSEN [15]. The software enables to simulate the hydropower station dynamics, taking into account hydraulic machinery and systems, electrical machines, power electronics and the control systems, as illustrated in Fig. 16. SIMSEN serves as a backbone to assessing the true hydropower renovation potential by considering both electric generation increase and services provided to the grid.

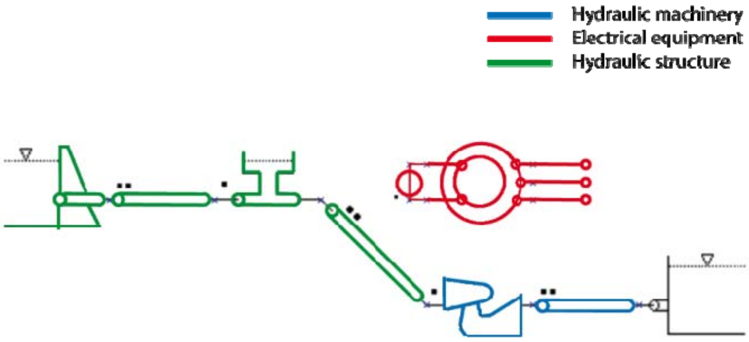

Fig. 16. Illustration of the multi-disciplinary project approach in the SIMSEN software

The multi-disciplinary RENOVHydro project consists of developing a new SIMSEN library to support the decision-making process for the renovation of hydraulic power plant with the ability to overcome huge number of combinations experienced at early design stages, when each decision has a major impact on the final performance of the hydropower plant. Numerous scenarios for the hydraulic structures, hydraulic machinery and electrical equipment are evaluated by an automated engine. The provided scenario explorer highlights the synergies between the different fields of engineering involved. This high level of support for the decision-making process of the stakeholders will drastically reduce the risks of selecting a suboptimal solution.

The SIMSEN numerical models enable considering various hydraulic layout configurations, integrating non-linear head losses and realistic empirical turbine performance hill charts, generator efficiencies as well as operating flexibility offered by variable speed technology. Thus, each hydropower plant upgrade option can be assessed by considering the hydraulic structure, the generating units as well as the interaction of the hydropower station with the grid for the provision of ancillary services. This is demonstrated in the RENOVHydro project, delivering a unique methodology for the independent assessment of a high number of possible civil and electromechanical modifications. Important energy and economic indicators, such as annual energy generation, annual amount of turbined/pumped water, energy coefficient, investment cost, profitability and ancillary services for each renovation option, are analysed to identify the most promising technical trends for a given political, economic and environmental context, (see [16] and [17]). The overall methodology of this systematic study is illustrated in Fig. 17.

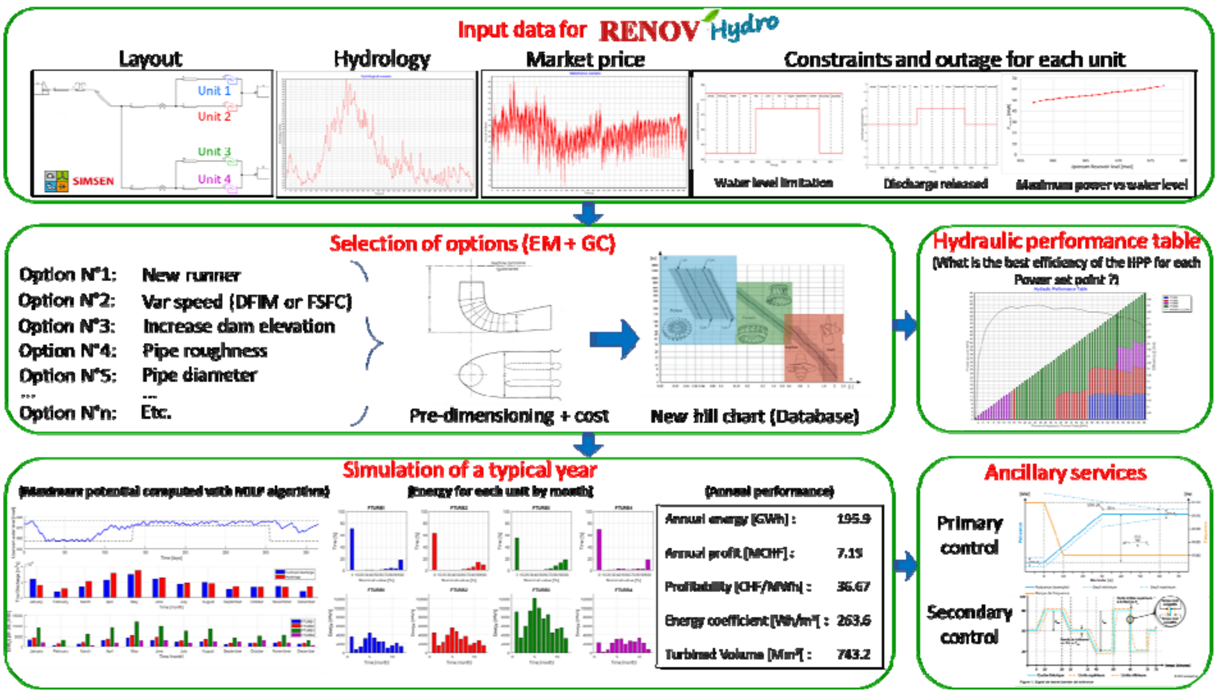

Fig. 17. RENOVHydro workflow

3.2 The FLEXSTOR project: preventing turbine instability during multiple start/stop procedures.

The research project FLEXSTOR, standing for “Solutions for flexible operation of storage hydropower plants in changing environment and market conditions”, brought together the members of the *Swiss Competence Center for Energy Research – Supply of Electricity* (SCCER-SoE) and the utility KWO to improve the climate and market resilience, as well as the eco-compliance, of Switzerland. New tools and methodologies have been proposed for future design and operation of flexible hydropower schemes and applied to KWO's power plants. HES-SO Valais, KWO and EPFL LMH investigated the impact of frequent start-up and stand-by operation on hydraulic machines using advanced numerical and experimental approaches, which are on the cutting edge of present developments. The case study of the Grimsel 2 pumped-storage power plant has been selected. The Francis turbines of the four ternary groups undergo strong fluid-structure interactions during some operating conditions, which led to premature cracks on the runner blades, thus reducing their life-time. Preliminary numerical simulations have been carried out and compared to available data for the nominal operating conditions. The objective was to define a numerical methodology to predict possible flow instabilities which should be behind the cracks’ development in off-design conditions. In parallel, an experimental investigation of one of the Francis turbine prototypes, part of a ternary group, has been carried using both onboard runner and external non-intrusive instrumentation. The measurements evidenced the existence of harmful conditions for the runner at Speed No Load (SNL) during the synchronization of the turbine with the grid and during the shutdown phase.

Fig. 18. Experimental setup for onboard and stationary instrumentation for FlexSTOR.

In addition, a FEM modal analysis allowed computing the Eigenmodes of the turbine runner and the one way coupling between CFD and FEM allowed estimating the runner deformation and the mean stresses due to the flow pressure. Using all the experimental and numerical results, a scenario for the onset of the harmful structural loading is provided. This scenario suggests that an Eigenmode of the runner could be partially excited at very low guide vanes opening leading to the apparition of the cracks due to the overtaking of the fatigue limit of the runner.

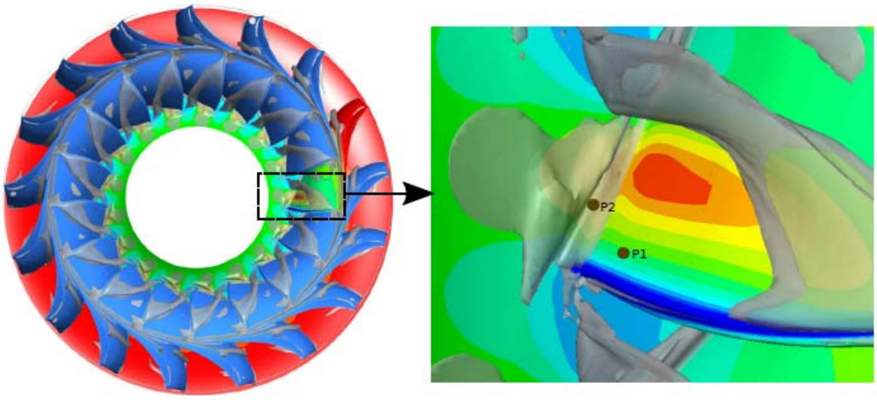

Fig. 19. Numerical flow simulation in the runner for FLEXSTOR.

Finally, this study shows that the critical operating conditions, which are easily detectable through the onboard measurements, may also be successfully identified while using only the non-intrusive measurements in the stationary frame. Coupled with the numerical approach, it provides a smart and powerful diagnostical tool for other machines suffering from similar problems (see [11], [12], [13] and [14] for further documentation).

4. Progress through collaborative European research initiatives

Providing reliable grid regulation services is one of the keys to unlocking hidden hydro potential. Therefore, in parallel to the national initiatives described in this paper, targeted research is performed and promoted in large European collaborative research projects. The HYPERBOLE project (FP7-ENERGY-2013-1 – N° 608532) investigated extensively how flexibility can be provided to the EPS through off-design operation of hydropower plants and variable speed pump-storage power plants. A list of publications can be found online [18].

The even bigger follow-up project is XFLEX (Horizon 2020 innovation action N° 857832), beginning in September 2019 and uniting a consortium of 19 leading hydropower stakeholders across Europe. The hydropower industry will not be spared from digital disruption. Machine learning and advanced data processing and equipment control technologies open new horizons with enormous potential when combined with proven technical solutions, such as electrochemical storage hybrid- or variable speed generators. The project, where Switzerland is represented by EPFL, ALPIQ, Andritz Hydro, PVE and HES-SO, has two main goals:

1. To demonstrate how to increase the potential of the hydroelectric technologies in providing flexibility to the electric power system while achieving an improved average annual overall efficiency of the hydroelectric machinery, providing high availability of the hydroelectric power plants and further maximizing their performances;
2. To demonstrate the system integration methodology of hydroelectric technology solutions such as fixed and variable speed, pump power regulation, battery hybridization, advanced monitoring and digitalization, and to draw the road-map for the deployment of this system integration to the all kinds of European hydroelectric power plants, run of river, storage and pumped storage of all sizes; existing, uprated or new.

As one of the principal outputs a Smart Power Plant Supervisor (SPPS) will be developed. The SPPS is based on a multi-hillchart system, an empirical digital approach whose variables are the key parameters for the optimization of the hydroelectric unit operation, such as its performance in terms of energy, efficiency, cavitation and pressure fluctuations, as well as its residual lifetime by considering the wear and tear and structural fatigue. Moreover, sophisticated models for the electricity demand and price will be included, thus finally enabling the operators and owners to use their assets at precisely the optimal point at all times. Experimental data feeding the program will be generated by reduced scale model tests at the experimental testing facilities of EPFL LMH for three of the XFLEX demonstrators (the Z'Mutt reversible pump-turbines in Switzerland, the Alto Lindoso Francis turbines in Portugal and the Vogelgrün Kaplan turbines in France). Innovative technologies to provide EPS flexibility will be tested, such as the hybrid operation of a battery energy storage device with a hydroelectric generating unit to provide fast regulating power for primary frequency regulation or grid synchronization, while reducing the start-and-stop operations of the turbines and thus prolonging their life cycles. The XFLEX project will define comprehensive guidelines for an industrial deployment of the developed technology, as it is highly probable that SPPS inspired solutions are going to be the new standard for both greenfield and refurbishment hydroelectric projects.

5. Conclusions and perspectives

This paper demonstrates that there is yet significant potential for hydropower to be uncovered in general, and how this is being achieved in the case of Switzerland. Joint efforts are addressing a broad range of technologies and scales. In parallel to new projects, small hydropower plants at existing structures are promoted as cost effective solutions with a low environmental impact. Financial viability is further improved by studying and demonstrating how the extension of their operating range enables the small hydropower plants to provide ancillary services to the electric power system. In addition, innovative new turbine types are being designed for the use in drinking water networks and open channel flows, again with ongoing demonstrators. Significant efforts are also undertaken to optimize the operation and the stepwise renewal of the existing hydropower fleet. Powerful decision-making tools are developed to select the ideal solution among many, considering all the relevant technical, financial and environmental aspects. Finally, the dynamic loads on hydromechanical equipment during transient and off-design operation are measured and simulated in a goal to further increase flexibility and prolong lifecycles.

The cited projects are of transdisciplinary nature and require input from various fields and levels. National initiatives, such as the *Swiss Competence Centers for Energy Research*, are an ideal way of grouping partners from different backgrounds and for initiating fruitful collaborations. The availability of suitable funding instruments is of course a prerequisite. Furthermore, it has been shown that incentives for pushing the boundaries can be provided through sensible energy policies.

Acknowledgements

The authors would like to thank Christian Landry from PVE, Daniel Biner, Jean Decaix, Vlad Hasmatuchi, Shadya Martignoni and Olivier Pacot from HES-SO and Laurent Smati, Aline Choulot and Alberto Bullani from Mhylab for their contributions to the research projects cited in this paper. The small pumped storage hydropower project was supported by the *Services Industriels de Genève* (SIG) and the *Swiss Competence Center for Energy Research – Future Swiss Electrical Infrastructure* (SCCER-Furies). The SmallFLEX project is supported by the *Swiss Federal Office of Energy* (SFOE), the *Forces Motrices Valaisannes* (FMV) and the *Swiss Competence Center for Energy Research – Supply of Electricity* (SCCER-SoE). The Duo Turbo project was funded by the *Commission for Technology and Innovation* (CTI, Grant funding 17197.1 PFEN IW) and the SCCER-SoE. The hydrokinetic turbine project was supported by the SFOE and the Fondation *The Ark*. The RENOVHydro project is funded by the CTI (Grant funding 19343.1 PFEN-IW) and the SFOE (Grant funding SI/501436-01). The financial and technical support of Groupe E and FMV are also kindly acknowledged. The FLEXSTOR project was supported by the CTI (Grant funding 17902.3 PFEN-IW) and KWO.

References

[1] **Association suisse pour l'aménagement des eaux, ASAE**, "Droit de retour et renouvellement de concession des centrales hydroélectriques", Fiche d'information, Novembre 2012, 3 pages.

[2] **Cottin, C., Choulot, A., Denis, V.**, "Multipurpose schemes: feedback on electromechanical equipment set within drinking water networks", Proceedings, Hidroenergia 2012, Worclaw, Pologne, session VIB, May 2012.

[3] **Choulot, A., Denis, V., Punys P.** "Integration of small hydro turbines into existing water infrastructures", Hydropower - Practice and Application, Dr. Hossein Samadi-Boroujeni (Ed.), ISBN: 978-953-51-0164-2, InTech, 2012.

[4] **Choulot A., Denis V.**, « Energy Recovery in existing infrastructures with small hydropower plants, Multipurpose schemes – overview and examples », Shapes, 6th framework program, European Commission, June 2010.

[5] **Martignoni S., Smati L., Denis V., Münch** C. "Un stockage local et compétitif de l'énergie", Bulletin ElectroSuisse, 2/2018, pp. 27-31.

[6] **Zordan, J., Gaspoz, A., Manso, P., Münch-Alligné, C., Crettenand, S., "**Introducing flexibility in alpine small hydropower plants using smart storage", *Proceedings*, Hydro 2019, October 14-16, 2019, Porto, Portugal.

[7] **Biner D., Hasmatuchi V., Violante D., Richard S., Chevailler S., Andolfatto L., Avellan F. and Münch C.,** "Engineering and performance of DuoTurbo: microturbine with counter-rotating runners", *Proceedings*, 28th IAHR Symposium on Hydraulic Machinery and Systems, 2016, Grenoble, France.

[8] **Biner, D., Andolfatto L., Hasmatuchi, V., Rapillard, L., Chevailler, S., Avellan, F. and Münch-Alligné, C.,** "DuoTurbo: A New Counter-Rotating Microturbine for Drinking Water Facilities", *Proceedings*, International Conference on Innovative Applied Energy (IAPE'19), March 14-15, 2019, Oxford City, United Kingdom.

[9] **Samora I, K, Essyad, Biner, D, Münch-Alligné, C.,** "Hydropower in urban drinking water distribution networks", *Proceedings*, Hydro 2019, October 14-16, 2019, Porto, Portugal.
[10] **Münch-Alligné C., Schmid J., Richard S., Gaspoz A., Brunner N., Hasmatuchi V.** "Experimental Assessment of a New Kinetic Turbine Performance for Artificial Channels", *Water*, 10(3), 2018.
[11] **Decaix J., Hasmatuchi V., Titzschkau M., Münch-Alligné C.,** "CFD investigation of a high head Francis turbine at speed no-load using advanced U-RANS models", *Applied Sciences*, 8(12), 2018.
[12] **Hasmatuchi, V., Decaix, J., Titzschkau, M. and Münch-Alligné, C.**, "A challenging puzzle to extend the runner lifetime of a 100 MW Francis turbine", *Proceedings*, Hydro 2018, October 14-17, 2018, Gdańsk, Poland.
[13] **Decaix, J., Hasmatuchi, V., Titzschkau, M., Rapillard, L., Manso, P., Avellan, F. and Münch-Alligné, C.,** Experimental and numerical investigations of a high-head pumped-storage power plant at speed no-load", *IOP Conf. Series: Earth and Environmental Science*, 240(8), 2019.
[14] **Hasmatuchi, V., Decaix, J., Pacot, O., Titzschkau, M. and Münch-Alligné, C.**, "Detection of harsh operating conditions on a Francis prototype based on in-situ non-intrusive measurements", Hydro 2019, Porto, Portugal, 2019
[15] https://simsen.epfl.ch
[16] **Landry, C., Nicolet, C., Gomes, J., Andolfatto, L., Avellan, F., Todde, C.**, "Renovation of hydraulic power plant: how to select the best technical options?", *Proceedings*, Hydro 2018 (paper 30.05), October 14-17, 2018, Gdańsk, Poland.
[17] **Landry, C., Nicolet, C., Gomes, J., Avellan, F.**, "Methodology to determine the parameters of the hydraulic turbine governor for primary control", *Proceedings*, Hydro 2019, October 14-16, 2019, Porto, Portugal.
[18] https://hyperbole.epfl.ch

The Authors

A. Müller studied mechanical engineering at the Swiss Federal Institute of Technology in Lausanne (EPFL), and at the Royal Institute of Technology (KTH) in Stockholm, Sweden. He completed his doctoral studies of flow instabilities in Francis turbines at the EPFL Laboratory for Hydraulic Machines (EPFL LMH) in 2014. His industrial experience includes working for ABB Switzerland Ltd. from 2008 to 2010, specializing in the rotor-dynamics of large high-speed electrical machines, and, from 2016 to 2019, for the small hydropower equipment supplier Nippon Koei Co., Ltd. in Japan, both in the Hydro Plant Planning Office and in the Market Development Office. Since April 2019 he is responsible for the reduced scale model testing at EPFL LMH.

C. Münch-Alligné obtained an engineering degree from INPG, Grenoble, France, in 2002. She then obtained a grant from the CNRS and the CNES to start a PhD thesis on large eddy simulations of compressible turbulent flows. She defended her doctoral degree in 2005 at the INPG. From 2006 to 2010, she worked as a research associate in the EPFL Laboratory for Hydraulics Machines on flow numerical simulations in hydraulic turbines. Since 2010, she has been a Professor at HES-SO Valais/Wallis, School of Engineering in Sion, Switzerland. She is Head of the hydroelectricity research team. Her main research interests are hydraulic turbomachinery, numerical simulations, performance measurements, turbulence and fluid-structure interactions.

C. Nicolet received his MSc degree in mechanical engineering from the Swiss Federal Institute of Technology in Lausanne (EPFL) in 2001. He obtained his PhD in 2007 from the same institution in the Laboratory for Hydraulic Machines (EPFL LMH). Since, he is managing director and principal consultant of Power Vision Engineering Sàrl in Ecublens, Switzerland, a company active in the field of optimization of hydropower transients and operation. He is also external lecturer at EPFL in the field of transient flow.

V. Denis holds MSc degrees in both mechanical engineering and energy systems from the Swiss Federal Institute of Technology in Lausanne (EPFL). He worked for four years in the hydroelectric department of an international consulting engineering company, mainly on hydro projects in Switzerland and India and on drinking water network and pumping stations in Morocco. He then joined Mhylab, where he is now the managing director and board member, in charge of research and development projects for small turbines and of engineering projects. He is involved in projects in Europe, Oceania and Africa. For more than 15 years, he has also been involved in training and teaching activities. He is an expert for the EU Horizon 2020 program and for the UNDP. Since 2016, he is a member of the steering committee of the conferences organized by Aquamedia International and regularly chairperson in Hydro conferences.

F. Avellan graduated in hydraulic engineering from Ecole Nationale Supérieure d'Hydraulique, Institut National Polytechnique de Grenoble (INPG), France, in 1977. In 1980 he received his doctoral degree in engineering from University of Aix-Marseille II, France. Starting as a research associate at EPFL in 1980, he became director of the EPFL Laboratory for Hydraulic Machines (EPFL LMH) in 1994 and was appointed Ordinary Professor in hydraulic machinery in 2003. His main research areas are hydrodynamics of turbines, pumps and pump-turbines, including cavitation, hydroacoustics, design, performance and operation assessment. Prof. Avellan was Chairman of the IAHR Section on Hydraulic Machinery and Systems from 2002 to 2012.