Electricity supply and hydropower development in Switzerland

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Introduction

According to the Swiss Energy Strategy 2050, which takes into account the phase out of the existing nuclear power plants, the mean annual hydropower production must be increased by 1.5 TWh/a under present framework conditions, eventually reaching 3.2 TWh/a if conditions are optimized (SFOE, 2016). In view of environmental and socio-economic constraints, this foreseen increase is extremely challenging and can be reached only by innovative and sustainable solutions for new hydropower plants (HPP) and by the extension and optimization of existing schemes including reservoirs. Furthermore, the expected increase of power production from small hydropower plants (SHPP) requires the development of criteria for a careful site selection as well as strategies to optimize power production within a river network while at the same time minimizing the negative impacts on stream ecology.

In this context, the Swiss Government is funding since 2013 a Swiss Competence Center for Energy Research on Supply of Electricity (SCCER-SoE) with the aim of developing fundamental research and innovative solutions in the fields of geo-energies and hydropower. Given the recent and present harsh contextual conditions, there is a growing consensus rather to favour the extension of the existing large hydropower schemes and reservoirs than to exploit the last natural rivers with a large number of small hydropower plants. Also, the effect of climate change will not only change the availability of water resources in time but also change the behaviour of the catchment areas by an increased sediment yield into reservoirs and more frequent natural hazards, and thus considerably endangering waterpower production in the near future. In fact, the critical period of electricity supply in Switzerland is still the winter semester (October-March), period during which on average 3.7 TWh have been imported over the last 12 years, which is almost 11% of the electricity demand in winter. In order to guarantee a safe energy supply also during critical periods, Switzerland has to increase its storage capacity by new reservoirs where possible and mainly by increasing the volumes of existing ones.

The paper presents the current context for energy transition and hydropower development in Switzerland, summarizes the activities on hydropower infrastructure research carried out over the past 3 years and presents the development objectives for the coming four years. The focus is on the increase of operational flexibility and winter production. The plan includes three demonstrators, the first on recently commissioned small-hydro schemes, the second on sediment release through the powerhouses and the third being a multidisciplinary project in the multi-reservoir multi-powerplant scheme operated by Kraftwerke Oberhasli in the Bernese Oberland.

1. Current context and challenges

Already today, Switzerland plays, thanks to its storage power plants, an important role in supplying peak energy in the European grid and thus contributes significantly to its frequency control. In the future, this position has to be reinforced with the goal to become one of the main batteries in Europe able to supply peak energy at any time. The forced and subsidized European production of mainly solar but also wind energy will further increase the need for regulation and peak energy. After reduction of European subsidies and actual market price distortions, and after economic recovery in Europe, the attractiveness of new pumped-storage power plants, the increased reservoir volume by dam heightening as well as the increased installed capacity of existing power plants by adding new parallel waterway systems and powerhouses will be highly attractive again. Rendering Switzerland's hydropower production more flexible in the future with the purpose to concentrate it at times of high peak demand is a must for guaranteeing a leading position of Switzerland in a highly competitive electricity market in Europe. Such hydropower production focused on peak energy will have more severe effects on river flow regimes, so-called hydropeaking, which have to be assessed and mitigated by innovative measures

Increase of reservoir capacity

There are only a few sites left in Switzerland for the construction of new large dams and reservoirs. Nevertheless by moderate heightening of the existing dams, which means by less than 10% of initial height, an additional reservoir volume of 700 million m^3 could be created as sum of about 20 feasible projects. This would allow increasing the winter electricity production by 2 TWh, which corresponds to 10% of the actual winter generation. Considering that some dams could be heightened even more, electricity production in winter could be even enhanced by about 15%. This is not only important for a safe and independent electricity supply in Switzerland but also significant for grid stability in Central Europe.

Fig. 1. Muttsee Gravity dam under construction (Schleiss 2012)

Fig. 2. Vieux Emosson Arch dam under construction (Schleiss 2013)

Swiss engineers have acquired high competences in heightening and retrofitting of existing dams within the country and abroad. Several large dams have been already heightened as Mauvoisin arch dam by 13.5 m to 250 m between 1989 and 1991 as well as Luzzone arch dam by 17 m to 225 m between 1995 and 1999. Recently the Muttsee reservoir has been enlarged by the construction of a 35 m high and 1.2 km long gravity dam (see Fig. 1). In 2014 heightening of Vieux Emosson arch gravity dam by 21.5 m was successfully achieved (see Fig. 2). Further projects are foreseen.

In high-mountain regions glacier retreat due to global warming will become an opportunity to adapt existing hydropower schemes and future projects to this new reality. In the Alps, the melting of glaciers first produces over the near future an increase of the average annual discharge depending on glacier and catchment characteristics, especially during the summer season. Nevertheless after a certain time, significant decrease of runoff related to glacier melting in summer on one hand and significant increase of snowmelt runoff in spring on the other hand must be considered for reservoir operation. Moreover, melted glaciers will free new alpine valley areas, which have a potential for the construction of new dams and reservoirs.

For example the retreat of Trift Glacier in the central Swiss Alps has already created a new lake and a project for a 180 m high arch dam is under preparation for concession approval (see Fig. 3).

Increase of pumped-storage capacity

Several project have been launched recently to increase the pumped-storage capacity of existing powerplants (e.g. Hongrin-Léman, Z'mutt, KW Linth-Limmern) or add the pumped-storage functionality to existing conventional plants (e.g. Nant de Drance on Emosson). These schemes add operational flexibility to the plant owner and to the grid operator. Several other projects have been identified and may take-off in coming years once the context uncertainties return to acceptable levels.


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Fig. 3. Photomontage of the future 180 m high Trift dam, which uses the already freed valley by glacier retreat.

2. Recent research on hydropower

Key research directions 2013-2016

In order to address the future challenges of hydropower and reservoirs development and to contribute to the Swiss energy strategy, the following key research directions are developed in the framework of the Swiss Competence Center for Energy Research under the ongoing program Supply of Electricity (SCCER-SoE). Research is carried out to investigate:

a) the change of production potential due to effects of future climate forcing, which are expected to impact water availability (glacier retreat, snow accumulation and melt, streamflow regimes, and sediment production and transport) as well as the operation safety of structures in view of new natural hazards (floods, slope instabilities, etc.);
b) the efficiency improvement of existing HPPs and reservoirs, which can be achieved by their expansion to allow a more flexible operation to accommodate new and highly fluctuating demands;
c) the contribution of new technological solutions to adapt existing infrastructures in view of increasing their efficiency of production and achieving higher operation flexibility during seasonal and daily peak demands, while maintaining the same level of (infra)structural safety and supply security;
d) the assessment of the effects of HPPs new and harsher operation regimes and increased numbers of SHPs on aquatic ecosystems and the development of strategies to reduce these impacts (e.g. by developing innovative strategies of environmental flow releases);
e) the definition of future boundary conditions for the operation of HPPs and reservoirs based on the development of electricity demand and market dynamics under uncertain social, economic and political forcing;
f) the assessment of multi-objective operation strategies of HPP systems, which maximize power production, reliability and flexibility of supply, profitability of operation and ecosystem conservation, under the constraints of a more fluctuating demand – due to higher fraction of renewable production – and an uncertain market.

A 10-years roadmap identified the following challenges: a) Effects of climate change and natural hazards, reservoir sedimentation, b) Electricity demand and energy market, concession renewal, c) Winter and peak energy production, opportunities of new reservoirs, d) Environmental flow, flow regime alteration, e) Severe operation conditions and safety of hydro-power infrastructures.

Key research output 2013-2015

In general the 10-years work plan will be achieved by about 30% at the end of 2016. More in detail, the following results have already been achieved. The key research output of the first three years of coordinated research in the field of hydropower is presented in the Science Report (SCCER-SoE 2015).

Task 2.1 Morphoclimatic controls: New sediment transport measurement, new airborne radar system for glacier mapping, development of a new stochastic weather generator for climate scenarios downscaling; field measurements of reservoir sedimentation and desilting basin; preliminary assessment of hydrological dam safety (flood risk) under climate change forcing.

Task 2.2 Socio-economic drivers: Optimizing hydro operation across different market segments to assess the value of hydro flexibility in the current and future market environments and investment model using real options to account for uncertainties.

Task 2.3 Infrastructure adaptation: HydroGIS Interactive Database; Swiss hydropower potential on wastewater systems, hydropower and energy efficiency in water networks; methodology for hydropower design under uncertainty; methodology for the estimation of extreme floods at large dams; characterisation of hydraulic behaviour of surge tank orifices; non-intrusive and real time monitoring of pressure shafts and tunnels and new design guidelines; ; suspended sediment real-time monitoring techniques; replenishment of sediments downstream of dams – erosion and transportation process of artificial depositions; assessing the hydropower potential in the periglacial environment accounting for increased sediment yield; new complex operation models providing quantitative data to engineers but also to other stakeholders, for validation of the operation of demodulation basins based on the selection of an ecologic acceptable quantile of up-and down-surges in the river reach downstream of the powerhouse outlet.

Task 2.4 Environmental impacts: analysis of current environmental flow regulations; new project on optimizing environmental flow releases; field study on environmental impacts of small hydropower plants (SHPs); new project on assessing the status of floodplains affected by hydro-power operations and developing suitable management actions and restoration measures at the floodplain scale; quantification of thermo-peaking in larger Swiss rivers.

Task 2.5 Integrated simulation of hydropower systems: Assessment of climate change impacts on hydrology and hydropower operation under business-as-usual production targets; identification of current hydropower system operation and design of future optimal operating policies under changed water availability and energy market conditions (price and demand); development of integrated model prototype and preliminary test on pilot study sites.

Furthermore conferences cycles and international workshops were organized on actual work plan issues and finally open lectures on hydro (MOOC) in German and French were registered under ENERGYScope: Swiss energy transition: Understand to choose (www.energyscope.ch).

3. SCCER-SoE Research plan for 2017-2020

Overview

The innovation challenge from the technological point of view is to upgrade infrastructure as well as hydro- and electro-mechanical equipment of existing and new hydropower schemes for flexible operation under changed market and environmental conditions. This will be also a key issue in the period beyond 2020 during which a large number of concession renewals will take place, which concerns infrastructure responsible for more than half the Swiss hydropower production, mainly peak energy. Besides technology, the hydropower sector needs new approaches, methods, methodologies and tools for the design and operation of hydropower plants taking into account uncertainties.

The research objectives for the period 2017-2010 provide an update of our quantitative estimate of climate change impacts on HP production and highlight required adaptation strategies to cope with extreme events, natural hazards. It will also identify risks of future HP operation, as well as risk management strategies preventing compromising safety or loosing generation potential, both on the short-term (event management) and on the long term (to avoid that infrastructure forcing could lead to significant damages and finally to discontinue production).

Another challenge is the design of new projects and the upgrading of existing schemes under uncertainties. Investment payback have to be scheduled for more than 50 years and this in the light of upcoming concession renewals. The upgrade in Phase II of the integrated model developed in Phase I to simulate large HP systems will form the basis for investigating these issues, including accounting for the co-variation of the uncertainty drivers.

Finally, reservoir sedimentation is a main challenge not only for Swiss HP but also worldwide since this process is the only but significant threat of sustainable use of storage HP. Technical solutions will be investigated including a pilot and demonstration project. Pathways of technological developments to increase the efficiency of HP operation under constraints of sediment supply to reservoirs, expected to increase as a consequence of global warming in particular of permafrost and glacier retreat, will be provided.

The structural and operation requirements have to be ensured by innovative approaches, which allow to increase the flexibility of the Swiss HP, urgently needed to be successful in a high competitive and uncertain market.

Key research directions

The innovation potential is summarized according to 5 key research direction (KD) as follows:

KD I: **Adding flexibility to hydropower operation** – structural and operation requirements, for instance by exploring the operational value of streamflow forecasts, by investigating the technical feasibility and profitability of innovative solutions to recover energy on hydropower waterways, by developing innovative tools for the early-stage feasibility assessment of HPP extension and upgrade projects considering the provision of ancillary services (grid regulation), by developing a catalogue of solutions for adaptation of complex surge tanks, by investigating the new water, temperature and sediment dynamics in the receiving water bodies generated by future increased flexibility in hydropower operation, and by investigating the multidimensional impact of HP operation policies on downstream water bodies under changing climate and market conditions.

KD II: **Update of climate change impacts on HP production and required adaptation strategies**, with a particular focus on "winter-time HP production" (winter time is the critical season of the year) to address issues like those observed in 2015/2016 (dry antecedent conditions, low storage reservoir levels, shallow snow cover). A comprehensive ice thickness map of the glaciated areas of Switzerland will help identifying and evaluating future potential reservoir locations. Also, the integrated modelling effort from Phase I will be up-scaled to the regional level, looking at a networked system of HP plants, and investigating the potential for system upgrades and interconnections, in view of maintain and eventually further increasing the actual production levels, under the constraint of climate change effects, price markets and impact on downstream water bodies.

KD III: **Extreme natural events, hazards and risk of HP operation** – for instance with the further development of the "stochastic weather generator" for the assessment and projection of extreme events and natural hazards, especially to account for uncertainty due to inherent climate variability both in the present and in the future climate. Also, with the quantification of flood risks associated with glacier-lake outburst and potential contribution to increasing safety by means of new high-altitude storage dams. Other relevant topics are: computing landslide-generated impulse waves; assessment of extreme flood events accounting for uncertainty; and, assessment of alternative tax schemes and associated financial risk for HP companies via simulation of alternative options through integrated modelling.

KD IV: **Design of new projects under uncertainties**, by means of new methodologies for robust design of hydropower projects as well as of dam and reservoir level heightening, including dam safety issues, integrating uncertainties in the probabilistic design of steel-lined tunnels and shafts and developing robust planning and management approaches of new HP projects (or expansion of existing systems).

KD V: **Reservoir sedimentation and sustainable use of storage HP,** for instance investigating sediment cascade flushing; sediment venting through bottom outlets; future sediment yield of glaciated catchments; modelling reservoir sedimentation; operation of HPPs regarding sediment flushing and turbine abrasion; design and operation of Sediment Bypass Tunnels (SBTs); mitigation of hydro-abrasion at SBTs and hydraulic structures.

Most of the results of the mentioned innovation potential will be tested and validated at the three HP demonstrators presented hereafter.

Demo A - Adding flexibility to small hydropower plants

The idea is to show how small hydropower plants (SHPs) can provide winter peak energy and ancillary services, whilst remaining eco-compatible. The outcome of recent research by SCCER-SoE partners will be applied to a pilot facility with the aim of providing operational flexibility to the SHP owner and therefore harvest additional revenues. The addition of flexibility will be done by testing infrastructure, equipment or operational adaptation measures, 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 will concern a new SHP which is now under construction and will be commissioned in 2017. The selected SHP is designed to operate as run-of-the-river and has no open-air upstream storage. The following research and development questions will be investigated for the context of the specific newly commissioned small HP:

Q1: How can intra-day, intra-week or intra-monthly storage be cost-effectively added to a given scheme, on the headrace side, on the tailrace side or both?

Q2: What are the consequences of enlarging the operational range of the machines, lowering considerably the low operational head threshold?

Q3: How can meteorological forecast (short-term /now-casting) be best used for power generation, for prediction of sediment inflows and for optimization of the settling tank purges (and reduction of water losses)?

Q4: What are the consequences of a more flexible SHP operation on the downstream river reach, namely in terms of hydropeaking and river morphology and in which conditions can the river space downstream accommodate and/or attenuate favourably up- and down-surges and thermo-peaking effects?

The outcome of this Demonstrator will be a set of business models allowing the detailed assessment of the added-value of flexibility.

Demo B - SEDMIX Controlled fine sediment release from a reservoir by a hydrodynamic mixing device

The idea is to stir artificially the stored water in a dam reservoir to prevent sediment from settling and allow for the sediment to be conveyed downstream at acceptable rates through the turbines or bottom outlets (Figure 4). The sediment mixer is a circular pipe arrangement that is installed near the dam at the reservoir bottom at the in vicinity of the power intake. The facility is equipped with four nozzles releasing pressurized water jets and inducing sufficient upwind turbulence to maintain fine sediments in suspension, thus preventing them from settling near the dam. Fine sediment are then continuously released downstream the power waterways (without water and energy loss) at low concentrations. The operation of the sediment mixer can be operated following a turbidity current flood-driven event or be scheduled for periodical sediment release operations. The demonstrator mixer operates with a pump needing electrical power supply (at some locations this may be optimally replaced by gravity water supply). The mobile mixing devise (demonstrator) will be tested at several dams (1 to 3) to show its efficiency.

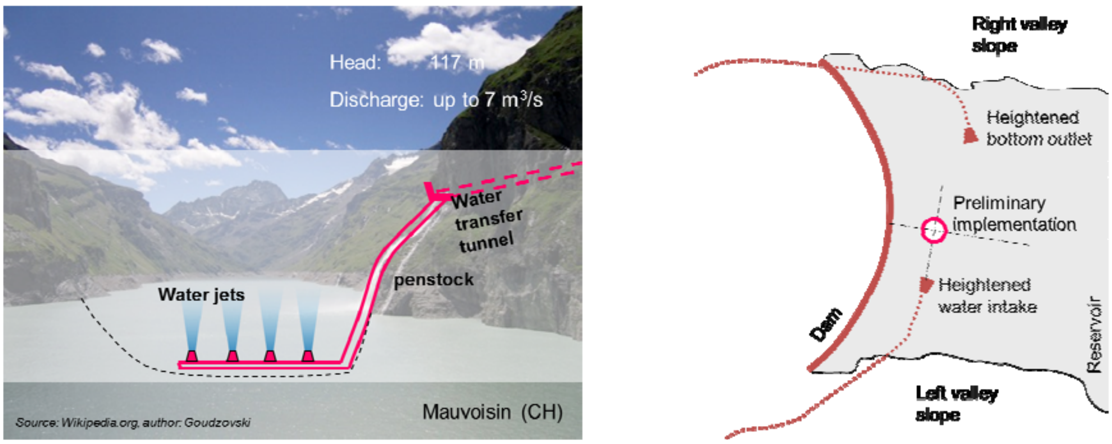

Fig. 4. Illustration of the Sedmix concept: left) applied to the Corbassière water transfer tunnel to Mauvoisin dam, right) preliminary implementation considering the local constraints of confinement (valley slopes, dam) which lead to complex asymmetric flow features (Jenzer-Althaus, 2011).

The demonstrator is composed of two main parts in steel construction: a water supply pipeline and a multi-nozzle manifold frame. It will be conceived for max. 200 m water depth and internal/external water pressure of 25 bar. The supply pipeline is mostly anchored onshore and the remainder lies on the reservoir bottom. The manifold circular frame is build onshore, then positioned with a system of water/air floaters/ballast using a motorized barge or tow boat. The facility can be installed on a given dam reservoir then disassembled & moved to another site. The operation of the demonstrator will be monitored regarding the water and energy input, as well as the water-sediment mix output through the waterways but also at selected control sections in the river downstream. The expected outcome from real-size field demonstrator is as follows:

- Validate flushing efficiency (per m3 of water release, per kWh of energy forced into the reservoir) as compared to laboratory development conditions;
- Identify dependency from local conditions (reservoir morphology, arrangement of reservoir inlets & outlets);
- Identify practical difficulties and shortcomings of field implementation and deployment;
- Identify bottlenecks and needs of future research and developments (e.g. modularity, junctions, SCADA).

The impact of the operation of this facility in the river downstream of the powerhouse will be assessed. The expected fine sediment concentration are expected to be far below the accepted turbidity levels. A preliminary implementation study has been already carried out for Mauvoisin reservoir in Valais (Jenzer-Althaus et al. 2014, 2016).

Demo C - FLEXSTOR pilot multidisciplinary project

FLEXSTOR will be a set of innovative tools for FLEXible operation of STORage hydropower plants in changing environment and market conditions. It will be developed and tested at a complex hydropower scheme, dealing with cutting-edge issues which are market opportunities or threats for Swiss hydropower with yet un-mastered risks. FLEXSTOR is motivated by the main hydropower challenge in Switzerland namely the need for flexible operation targeting premium remuneration hours, for which comprehensive methodologies for hydropower upgrading projects are still missing. Swiss hydropower is net provider of revenues annually to the country's economy, but at the moment on a negative trend. There is an important winter production deficit and therefore Switzerland is since more than 10 years a net importer in winter. Nevertheless storage hydropower plays a growing role in balancing EU's grid and in facilitating the integration of large shares of Solar and Wind electricity production.

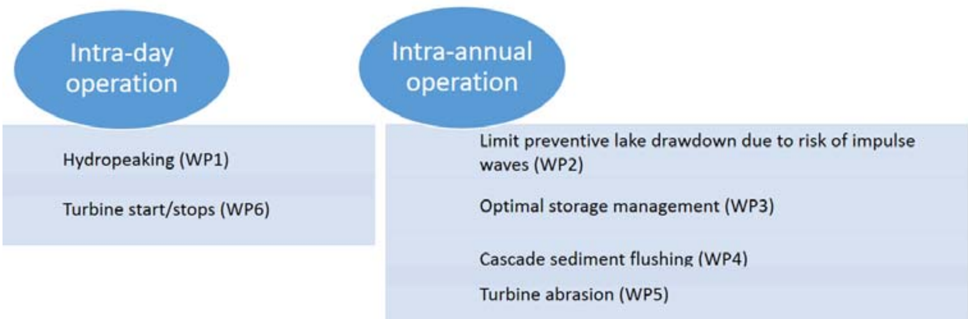

Fig. 5. FLEXSTOR project organization per work packages as function of the target timeframe for increased hydropower storage valuation.

Specific goals of FLEXSTOR are to demonstrate how production can be concentrated in less hours, while mitigating negative impacts (e.g. river up/down surges) and how reservoir sedimentation can be managed in a sustainable way to guarantee live storage and compliance with the Waters Protection Act in Switzerland Furthermore, mountain slope instability risks in periglacial zone will be addressed, avoiding non-optimal "preventive reservoir lowering". In addition the changing electricity demand structure and the required adaptation of the storage management will be identified. It will be also demonstrated that operating more rapidly and more frequently implies extending the operation range of hydraulic machinery, whilst avoiding instabilities. Finally the optimal management of a compensation basin in order to minimize the ecological impacts of hydropeaking in the downstream river reach will be addressed. All developments get their proof-of-concept in the complex system of KW Oberhasli, which allows for later replication to other hydropower schemes in Switzerland. The expected outcome from the real-size field demonstrator are as follows (Figure 5):

- Tools for coupled and flexible operation of storage power plants with eco-acceptable hydropeaking, site-calibrated considering the role of regulating equipment and 3D flow patterns inside the demodulation basin(s) and downstream river reach;
- Tools to predict thresholds of acceptable hazard risk of impulse wave generation, customized per reservoir operational conditions, and calibrated with identification of site-specific morphological features;
- Tools to predict the impact of flexible operational strategies of storage plants in providing valuable satisfaction of demand, highlighting the function of each reservoir's role on larger compounds of HPPs;

- Tools to predict the performance of co-ordinated sediment management in a cascade of reservoirs with reduced economic losses, site-calibrated as function of each reservoir's morphology;
- Quantitative identification of acceptable thresholds of turbine abrasion as function of fine sediment rates and impact on equipment lifetime and reservoir sedimentation, site-based on coupled sediment concentration and steel abrasion measurements;
- New procedures for start-stop paths of pump-turbines avoiding instability, springing from validated implementation of a first-ever on-board monitoring and testing of machinery at prototype scale in Switzerland.

4. Conclusions

The economic situation for Swiss hydropower industry will remain difficult during the upcoming years. There is a concrete risk is of losing significant technological, professional and scientific know-how, which will be required when the extension, rehabilitation, upgrading of Swiss hydropower has to take place beyond 2020 not only to contribute to the Energy Strategy 2050, but also to ensure sustainable competitiveness of Swiss hydropower in the enhanced European market.

It may be concluded that there will be still significant investments in hydropower and dams in Switzerland in future in order to overcome the challenges of safe and renewable electricity supply in a highly volatile and competitive market. These investments will be partially on the renewal and life extension of existing infrastructure and also on their upgrading and extension for flexible operation, meaning a few more peak hours per day and winter energy. Coping with climate changes is pushing the Swiss society to rethink issues as water storage and protection against floods and other natural hazards, for which resilient and fit-for-purpose hydraulic structures are paramount. Furthermore, recent developments at the National Council and Parliament level confirm that Swiss society is now ready to assess new projects of renewable energies considering these are of identical national interest as the protection of the landscape, matter that too often plummeted hydropower feasibility when compared to non-renewable energy sources more easily deployable.

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Dr Pedro Manso is a civil engineer with over 18 years of experience in the Water and Energy sectors, in particular in hydraulic works, dam engineering and water economics & management. He graduated from Lisbon University (IST/UL) in 1998 and started his career at DHV Portugal in the water & environment department. In 2000 he joined the Laboratory of Hydraulic Constructions (LCH) at the *Ecole Polytechnique Fédérale de Lausanne* (EPFL) where he conducted several engineering and research projects, and obtained in 2006 a PhD on the field of rock scour downstream of dam spillways. In 2003 he received the ICOLD honor certificate for the Next Generation and in 2006 the ASCE J. C. Stevens Award. From 2006 to 2014 he worked in Stucky Ltd in Lausanne as project engineer & manager for greenfield hydro projects and rehabilitation and upgrading of existing hydropower schemes and dams in Europe, Africa and Asia, including a 1-year term as Resident PM at Enguri arch dam and HPP in Georgia and a 2-year term as branch Director in Porto, Portugal. Since late 2014, he joined the SCCER-SoE and leads research on hydropower co-funded by electricity utilities and public agencies, seconded to LCH-EPFL. He currently mentors ten PhD and Master thesis altogether.

Prof. Dr Anton J. Schleiss graduated in Civil Engineering from the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, in 1978. After joining the Laboratory of Hydraulic, Hydrology and Glaciology at ETH as a research associate and senior assistant, he obtained a Doctorate of Technical Sciences on the topic of pressure tunnel design in 1986. After that he worked for 11 years for Electrowatt Engineering Ltd. in Zurich and was involved in the design of many hydropower projects around the world as an expert on hydraulic engineering and underground waterways. Until 1996 he was Head of the Hydraulic Structures Section in the Hydropower Department at Electrowatt. In 1997 he was nominated full professor and became Director of the Laboratory of Hydraulic Constructions (LCH) in the Civil Engineering Department of the *Ecole Polytechnique Fédérale de Lausanne* (EPFL). The LCH activities comprise education, research and services in the field of both fundamental and applied hydraulics and design of hydraulic structures and schemes. The research focuses on the interaction between water, sediment-rock, air and hydraulic structures as well as associated environmental issues and involves both numerical and physical modeling. Actually 19 Ph.D. projects are ongoing at LCH under his guidance. From 1999 to 2009 he was Director of the Master of Advanced Studies (MAS) in Water Resources Management and Hydraulic Engineering held at EPFL in Lausanne in collaboration with ETH Zurich and the universities of Innsbruck (Austria), Munich (Germany), Grenoble (France) and Liège (Belgium). Prof. Schleiss is also involved as an international expert in several dam and hydropower plant projects worldwide as well as flood protection projects mainly in Switzerland. From 2006 to 2012 he was Director of the Civil Engineering program of EPFL and chairman of the Swiss Committee on Dams (SwissCOLD). In 2006 he obtained the ASCE Karl Emil Hilgard Hydraulic Price as well as the J. C. Stevens Award. He was listed in 2011 among the 20 international personalities that “have made the biggest difference to the sector Water Power & Dam Construction over the last 10 years”. In 2014 he became also Council member of International Association for Hydro-Environment Engineering and Research (IAHR) and chair of the Europe Regional Division of IAHR. For his outstanding contributions to advance the art and science of hydraulic structures engineering he obtained in 2015 the ASCE-EWRI Hydraulic Structures Medal. After having served as vice-president between 2012 and 2015 he was elected president of the International Commission on Large Dams (ICOLD) in 2015.

Dr Manfred Stähli is a civil engineer with a PhD in Environmental Physics from the Swedish University of Agricultural Sciences. Since 2006 he has been heading the research unit Mountain Hydrology and Mass Movements at the Swiss Federal Research Institute WSL with approximately 40 people working in the field of Water Resources and Natural Hazard Management. His main expertise is on winter hydrology in alpine and northern-latitude areas, including snow and frozen soil. During the past five years he was (co-)author of two national syntheses on water resources under climate change and developed, together with his team, a drought early warning system for Switzerland.

Prof. Dr François Avellan, director of the EPFL Laboratory for Hydraulic Machines, graduated in Hydraulic Engineering from *Ecole nationale supérieure d'hydraulique, Institut national polytechnique de Grenoble*, France, in 1977 and, in 1980, got his doctoral degree in engineering from University of Aix-Marseille II, France. Research associate at EPFL in 1980, he is director of the EPFL Laboratory for Hydraulic Machines since 1994 and, in 2003, was appointed Ordinary Professor in Hydraulic Machinery. Supervising 36 EPFL doctoral theses, he was distinguished by SHF, *Société hydrotechnique de France*, awarding him the "*Grand Prix 2010 de l'hydrotechnique*". His main research domains of interests are hydrodynamics of turbine, pump and pump-turbines including cavitation, hydro-acoustics, design, performance and operation assessments of hydraulic machines. Prof. Avellan was Chairman of the IAHR Section on Hydraulic Machinery and Systems from 2002 to 2012. He has conducted successfully several Swiss and international collaborative research projects, involving key hydropower operators and suppliers, such as: (i) Coordination for the FP7 European project n° 608532 "HYPERBOLE: HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies" (2013-2017); (ii) Deputy Head of the Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE) to carry out innovative and sustainable research in the areas of geo-energy and hydropower for phase I (2013-2016) and Phase II (2017, 2010) to be approved. (iii) EUREKA European research projects: N° 4150 and N° 3246, "HYDRODYNA, Harnessing the dynamic behavior of pump-turbines", (2003-2011), N° 1605, "FLINDT, Flow Investigation in Draft Tubes", http://flindt.epfl.ch/, (1997-2002). N° 2418, "SCAPIN, Stability of Operation of Francis turbines, prediction and modelling"; (iv) Swiss KTI/CTI research projects with ALSTOM Hydro, Birr, SULZER Pumps, Winterthur and Andritz Hydro, Zürich.; (v) ETH Domain, HYDRONET Project for the Competence Center Energy and Mobility, PSI Villingen. Moreover, he is involved in scientific expertise and independent contractual experimental validations of turbines and pump turbines performances for the main hydropower plants in the world. In recognition for his work as Convenor of the IEC TC4 working group of experts in editing the IEC 60193 standard he received the IEC 1906 Award.