Harvesting the energy of existing infrastructure

Generating electricity from drinking water networks

In Switzerland, nearly 6% of electricity is generated from small-scale hydro-power, around 1,300 installations delivering nearly 3½ thousand gigawatt hours. An untapped potential of around 1½ thousand gigawatt hours has been identified. ***Professor Cécile Münch-Alligné*** *and colleagues from the University of Applied Sciences, Western Switzerland, Sion, collaborating with the EPFL Laboratory for Hydraulic Machines, Lausanne and Swiss industrial partners, Telsa SA, Jacquier-Luisier SA and Valéléctric Farner SA have developed a novel "plug-and-play" modular technology to tap part of this potential focusing on extracting energy from existing drinking water networks.*

Using the energy from flowing water for useful work has long been practised for many years. Ad-hoc installations, generating electricity to serve villages, have largely been replaced by electrical-grids fed by turbines, usually from large hydropower plants. Much of Europe is phasing out nuclear-generating capacity in favour of sustainable sources, such as hydro, wind, solar, tidal and biomass. In Switzerland, 5.7% of electricity is generated from small-scale hydro-power plants, each with an output that is less than 10 megawatts. Untapped sources, part of which being in existing infrastructures, could increase generation potential. On a drinking water network, a sustained head of water greater than 50m and a flow rate of more than a few litres per second is all that's required for a viable generator.

The focus of Professor Münch-Alligné and her research team is exploitation of these idle resources. They wish to develop a novel micro-turbine with high operational flexibility that can generate electricity from the drinking water network, with minimal interference with it – the installation being performed 'in-line' with little disruption.

AN IDEA IS BORN

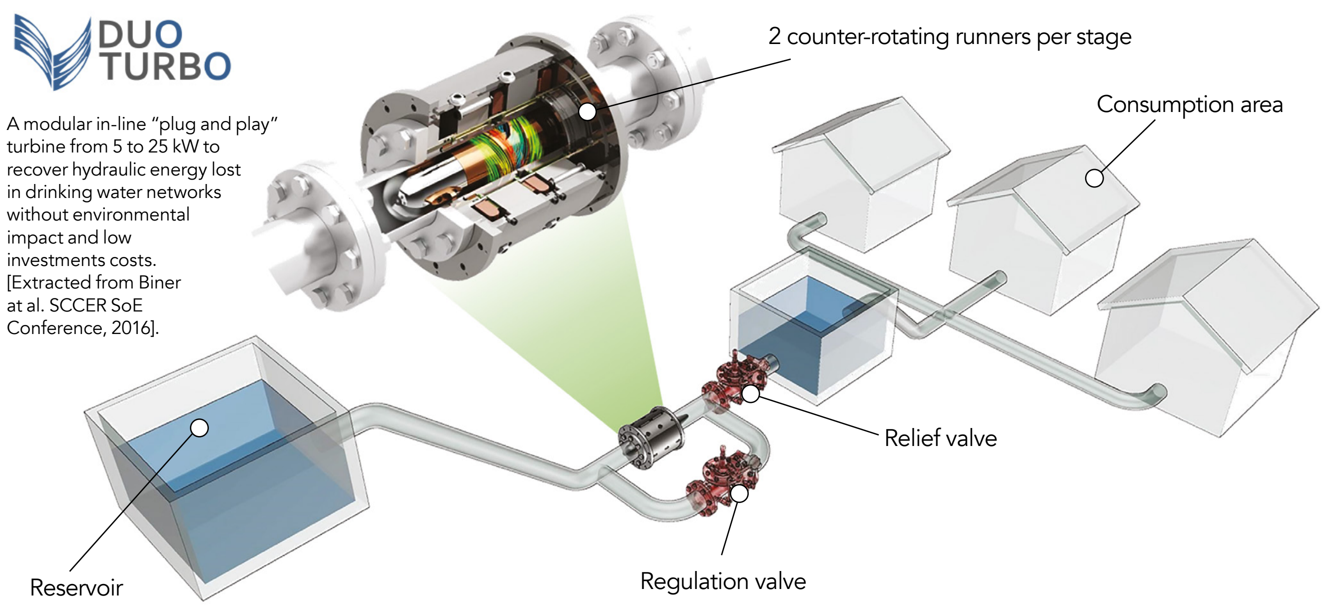
There is up to 1,600-gigawatt hours of energy available by tapping the hydraulic potential of small hydro in Switzerland. Easy to harvest, part of this potential lies in drinking water networks of alpine areas and, by doing this, electricity could be generated from existing infrastructures, with little capital investment and a low environmental impact.

The research team's solution is to exploit existing water networks, where pressure release valves dissipate the hydraulic energy surplus, estimating that between five and ten kilowatts of electrical generation capacity per site is feasible. By containing installation and running costs, many sites could be equipped, multiplying generating capacity to make a non-negligible contribution to Switzerland's energy needs.

ATTRACTING INTEREST

A novel design of a turbine with counter-rotating runners started as a student project at EPFL Laboratory for hydraulic machines. This idea later grew to several prototype developments at the University of Applied Sciences, Western Switzerland, Sion, and then to an industrialisation phase – attracting industrial partners: Telsa SA, Jacquier-Luisier and Valéléctric Farner. It resembles a streamlined torpedo, positioned axially in the water flow and generating electricity as it turns from the rim mounted generators, each turning in opposite directions. The independent speed regulation of each runner is a fundamental aspect and advantage of the design. Globally, those degrees of freedom would provide enhanced performance compared to alternatives (e.g., pump as turbine concepts), while keeping the mechanical complexity low.

The turbine needs to have a low impact on the drinking water networks in which it would be embedded. Therefore, the machine must be easy to install, have little maintenance and the likelihood of contaminating the water supply to be minimal. Professor Münch-Alligné and her team knew that requirements like these needed careful assessment, therefore, they used numerical methods, like computational fluid dynamics (CFD: using numerical methods to analyse fluid flows), to design the turbine runners. Simulations were also undertaken for the electricity generators, the mechanical structure and control electronics, but



A modular in-line "plug and play" turbine from 5 to 25 kW to recover hydraulic energy lost in drinking water networks without environmental impact and low investments costs. [Extracted from Biner at al. SCCER SoE Conference, 2016].

By containing installation and running costs, many sites could be equipped. Multiplying generating capacity would make a significant contribution to Switzerland's energy needs.

these computational approaches were not enough; the team needed to validate a prototype using a test rig and scrutinise pilot sites as a proof of concept.

UNDERSTANDING THE PROBLEM

The machine involves hydraulic, mechanical, electrical and electronical components. The requirement specifications and the interfacing between all parts must be well defined.

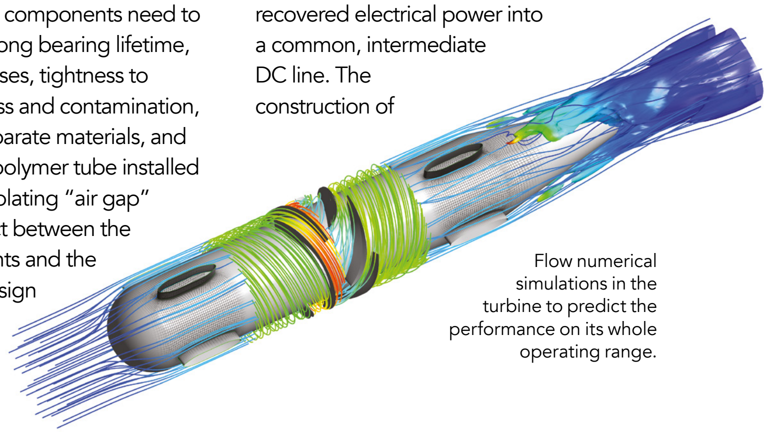
To understand the hydraulics, an existing drinking water system at Savièse, VS Switzerland was used as a case study because this network experiences large variations in both head (height between the upper and lower reservoirs provides the potential energy) and flow rate. Several sites have now been identified, and a second pilot, in the Verbier area, VS Switzerland, will also be equipped this year.

A basic design principle for the runners is that both normal operating and maximum power needs consideration. In addition, optimum performance required axial flow at the turbine outlet. Calculations were completed, determining the hydrofoil shape and blade cascade parameters of the ideal runner using established physical models (fundamental equation of turbomachines). The minimum axial blade length was imposed by mechanics, especially the needs of the rim mounted electrical generators. The number of blades chosen ensure a favourable blade density (ratio between cord length and blade pitch) and excellent hydrodynamic properties.

The mechanical attributes of the (tiny) 'DuoTurbo, micro-turbine' is novel and the challenges include: the compact nature of the turbine, that the components need to remain concentric, long bearing lifetime, minimum power losses, tightness to prevent water ingress and contamination, compatibility of disparate materials, and the wear profile. A polymer tube installed in the generator's isolating "air gap" prevents any contact between the electrical components and the fluid. A compact design (length 526 mm, diameter 300 mm) is essential. Linking each DuoTurbo into 'stages' allows excess hydraulic power to be utilised to increase generating capacity.

Custom-made generators positioned on the rim of the torpedo-shaped DuoTurbo convert the mechanical power to electricity and simulations validate the performance of the eight-pole neodymium permanent magnet synchronous generators. They confirmed that an average dynamic torque of around 10 Nm was reached at the 'nominal point' and, because runner distances were very small, stator windings are needed to be distributed over only half the circumference to minimise the distance between the generators, each generator windings offset by 90 degrees. Experimental tests confirmed a 92% electrical efficiency with a nominal output power of 3.37 kW per generator.

For the power electronics, two converters on the generator side are used to control the variable runner speed and to inject the recovered electrical power into a common, intermediate DC line. The construction of



Flow numerical simulations in the turbine to predict the performance on its whole operating range.

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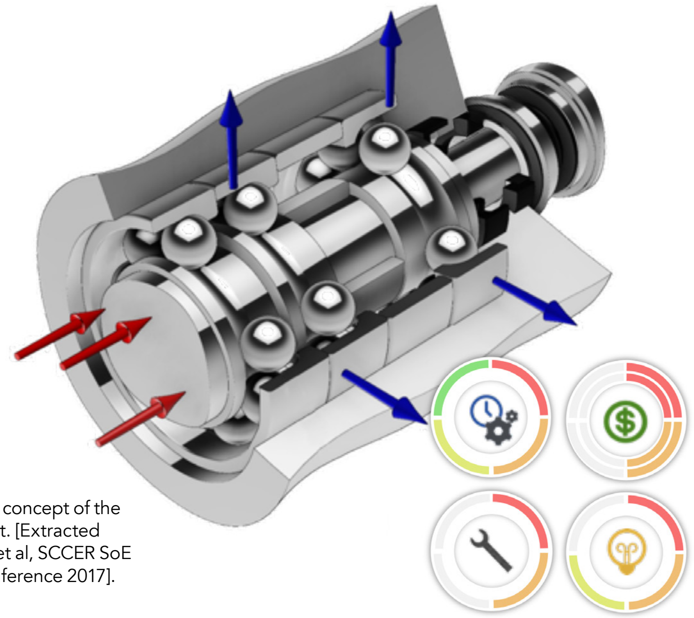
the DuoTurbo does not allow an encoder to be mounted, so the speed control is performed in sensorless mode. Finally, a third converter, connected to the DC line, injects alternating current into the electrical grid. A maximum power point tracking (MPPT) algorithm is employed to control the variable speed of each turbine runner for optimal performance during autonomous operation at the site.

VALIDATING THE SOLUTION

The research team developed a two-part, counter-rotating micro-turbine, shaped like a streamlined torpedo, that fabricates into a range of 'standard' energy recovery stations able to harvest electrical power from drinking water networks. Being 'plug-and-play' means low investment for customers and it has shown to be economic (when hydraulic conditions are suitable) generating between 5 kW and 25 kW. This year plans are in progress to equip two pilot sites in Valais, Switzerland.



Mechanical concept of the first product. [Extracted from Biner et al, SCCER SoE Annual Conference 2017].

Mainly steady-state computer simulations (numerical flow and structural, electromagnetic finite element) and experiments were used to design and validate the hydraulic, mechanical and electrical components – the electronic control circuits were purchased off-the-shelf. During the computational design stage, particular consideration was given to the variable operating conditions, in order to maximise the turbine's annual energy production.

The micro-turbine is compact, and several stages can be stacked, enabling exploitation of hydraulic power over a wide range. Each stage typically generates 5 kW for a 100 mm diameter duct. At the same time, the micro-turbine partially replaces the function of existing pressure release valves that protect downstream water systems from over-pressure.
Validation of the design is essential and was performed experimentally, in addition to the team's use of computational methods. The test rig at the University of Applied Sciences, Western Switzerland, Sion, was commissioned for the verification of the team's design. The hydraulic rig is fashioned to test small-scale turbines, pumps, valves and other hydraulic components. On two floors, the rig is supplied with fresh water from a reservoir and has three recirculating multi-stage variable speed centrifugal pumps (connected in parallel) to supply hydraulic power. A maximum discharge of 100 m³/h and pressure of 1.6 MPa (160 metres of water column) can be offered. A LabView® interface allows for testing to be controlled so that either the pump rotational speed, head or flow rate can be regulated.

During testing, the rig is used to record measurements for the DuoTurbo at a constant head, varying the rotational speed of the runners to register the characteristics of the full operating range. Efficiency measurements comprised mechanical and hydraulic efficiency, the latter being the energetic efficiency; leakage through the generator gap and the disc friction of the submerged electrical rotors reduce power conversion. Generator efficiency measurements were performed using a separate test configuration. Comparison between numerical simulations and experimental measurements showed a good agreement regarding the hydraulic characteristics of the turbine, allowing identification of power losses and evolution towards the most efficient design.

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THE RESULTS

The DuoTurbo micro-turbine has been developed for electrical energy recovery in drinking water systems to benefit from the hydraulic power surplus, normally dissipated by pressure release valves. The compact multi-stage design permits 'in line' installation with low investment costs, allowing 5-25 kW of power to be generated economically. The hydraulic, mechanical, electrical and electronic proof of concept was undertaken successfully, taking into account that drinking water systems provide variable discharge rates, to satisfy the needs of future implementation sites. Double rotational speed regulation ensures operational flexibility and is a significant advantage, compared to alternative technologies. Numerical flow simulations have confirmed the hydraulic constraints and an efficient blade design has been developed. Furthermore, testing has validated the computational analysis using the hydraulic test rig of the University of Applied Sciences, Western Switzerland, Sion. In addition to this, detailed analysis and modelling will continue, and endurance tests will be carried out at different pilot sites to assist in finalising the solution.

Behind the Bench

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Bio
Cécile Münch-Alligné is professor at the HES-SO Valais-Wallis, School of Engineering in Sion, Switzerland. She is head of the Hydroelectricity research group. Her main research interests are the development of new technologies for small hydro as well as the flexibility of large and small hydropower plants using numerical simulations and performance measurements.

Research Objectives
Exploit the untapped hydraulic potential of Switzerland's drinking water network by developing an in-line turbine to generate electricity with minimal impact on the network, simple installation, low cost of ownership and a small environmental footprint.

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Collaborators
- HES SO Valais-Wallis: Daniel Biner, Sylvain Richard, Shadya Martignoni, Sebastien Luisier, Vlad Hasmatuchi, Laurent Rapillard, Samuel Chevailler and the mechanical workshop
- EPFL Laboratory for Hydraulic Machines: Loic Andolfatto, Vincent Berruex, Elena Vagnoni, François Avellan
- Telsa SA: Steves Caloz
- Jacquier-Luisier SA: Claude Luisier
- Valéléctric Farner SA: Lucas and Christian Farner

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Personal Response

The DuoTurbo is in contact with the drinking water fluid. Have you assessed the likelihood of failure which could cause contamination of the water supply? What would be the impact?

The materials used for the turbine are authorised for drinking water networks. For the pilot sites, solely drinking water compatible stainless steel and polymers are used for submerged turbine components. The bearing lubricants are compatible for use with food products, in case of a severe mechanical damage of the bearing casing. Under normal conditions, a contamination of the water supply by the lubricants is excluded.