Technology, research and development

The craft of getting energy by using the power of water is well known and it has been used by mankind for centuries. The technology applied to profit from the pressure freed by falling water (waterfalls, rivers, reservoirs, streams or canals) is quite simple and it has been already exploited. Nevertheless, the following article will not only illustrate some basic principles about hydro technology but also shows how this technology, far from being mature and exploited, offers challenges for improvement, development, research and innovations!

Bernhard Pelikan
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There is a general misconception that because hydropower is a mature technology, there would be no significant prospects for future development or technological innovations. However, in reality, hydropower faces considerable research needs. In particular, in areas where untapped potential still exists in Europe, such as low-head and very low head installations, efficiency improvement of hydro units in refurbishment, multipurpose plants, fish-friendly turbines and other measures that improve environmental integration. Hydropower has still a significant untapped potential, not only in the development of new plants, but also in the upgrading (increase of efficiency and electricity production as well as environmental performance) of old ones.

SHP has a considerable, yet untapped potential, which will enable it to make a significant contribution to future energy needs

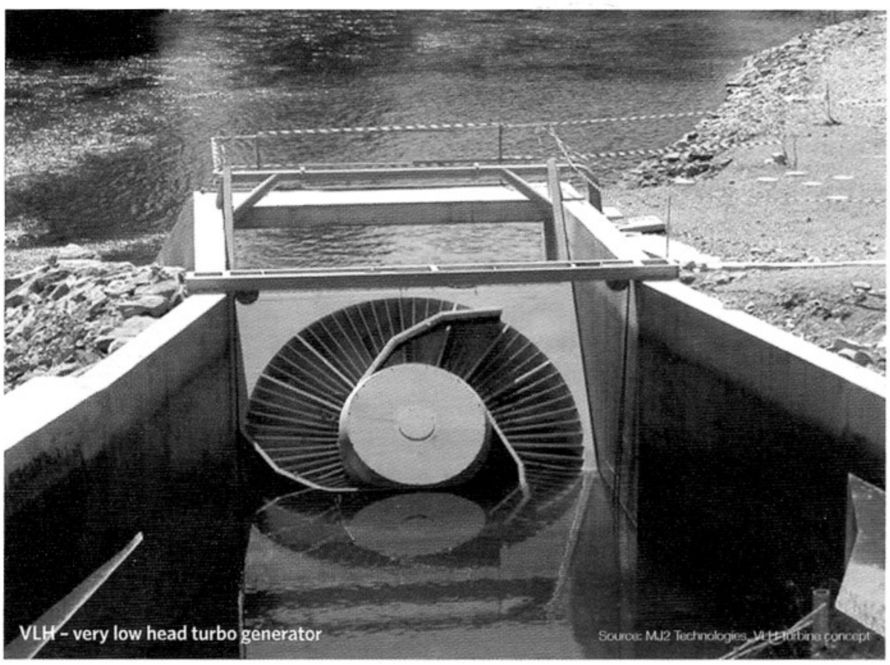
Small hydropower

Small Hydropower (SHP) has a key role to play in the development of Europe's renewable energy resources and an even greater role in developing countries. With the increased global electricity demand, the urgent need to cut down greenhouse gases and the fight against climate change and environmental degradation from fossil fuel use, there is an increasing interest in developing SHP. Indeed, SHP has a considerable, yet untapped potential, which will enable it to make a significant contribution to future energy needs, offering a very good alternative to carbon-based sources of electricity.

Today, small hydropower accounts for 12.5 GW installed capacity in the EU-27. It represents approximately nine per cent of the total hydropower installed capacity and approximately two per cent of the total electricity capacity installed in the EU-27. As far as production is concerned, total gross production of electricity was approximately 3,358 TWh in the EU, of which 344 TWh was supplied from hydropower. This means EU-27-generated hydropower represents 10 per cent of the EU's electricity production (in 2006).

Small hydropower can be one of the most reliable and economic methods to generate electricity. The concept is designed so that it can immediately respond to fluctuations in electricity demand, meeting both base-load and peak-load demand. Hydropower's chief advantage is that it provides a steady and secure source of electricity supply; it can thus counter the intermittency of other renewable energy technologies, such as solar electricity and wind. Thus hydropower, being the only source of flexible electric power, plays a crucial role in the safety and balance of our electric system.

A well-designed small hydropower system can blend in with its surroundings with very low environmental impact. SHP schemes are mainly run-of-river with little or no reservoir impoundment. Because it is fuelled by water, it does not pollute the



VLH – very low head turbo generator

Source: MJ2 Technologies, VLH turbine concept air or produce any other liquid or solid wastes. Other benefits may include a water supply during dry summer months and flood control, which are growing in importance with regard to climate change effects.

Small hydropower benefits

- Clean, sustainable and emissions-free source of renewable energy
- Highly efficient (from 70 per cent to 90 per cent)
- Proven and reliable technology
- Predictable and easy to manage
- Long lifespan up to 100 years
- Attractive energy pay-back ratio
- Improves grid stability
- It is an indigenous resource
- Improves the diversity of energy supply
- Technology suitable for rural electrification notably in developing countries

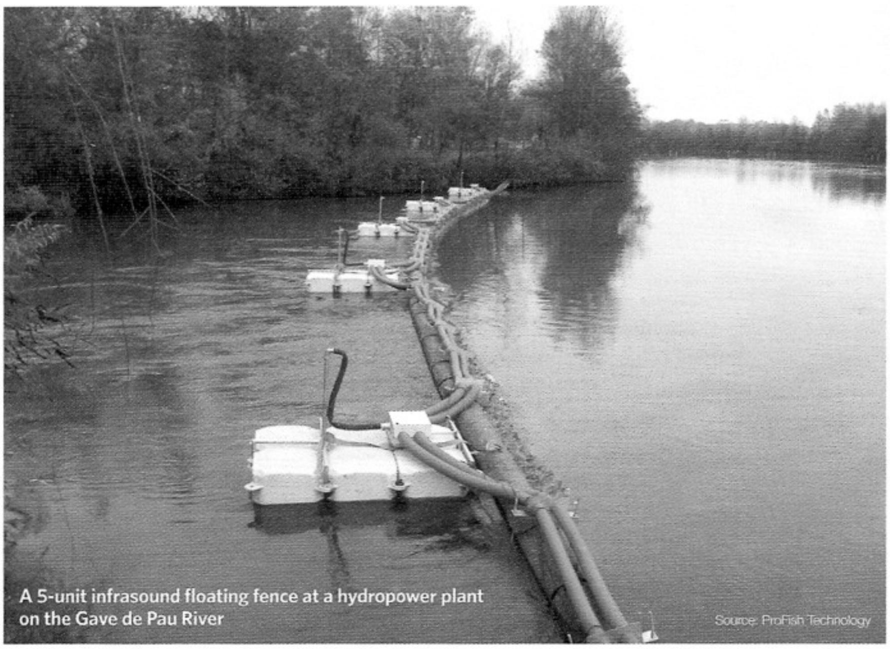
The climate change and energy package approved by European leaders in December 2008 was negotiated to combat climate change while reducing the EU's dependency on imported fuels. The current gas crisis has again shown us the dangers of strong reliance on external energy sources, using indigenous energy sources such as small hydropower would also reduce Europe's vulnerability to oil-price shocks and supply disturbances.

SHP can actively contribute to climate change mitigation. As an example, 1 GWh of electricity produced by SHP:

- Supplies electricity for one year to 250 households in a developed country
- Saves 220 tons of petrol
- Saves 335 tons of coal
- Avoids the emissions of 480 tons of CO_2
- Supplies electricity for one year to 450 households in a developing country

Technology

SHP schemes generate electricity or mechanical power by converting the potential energy of a mass of water, flowing in a stream with a certain fall (termed the 'head'), into electric energy at the lower end of the scheme, where the powerhouse is located. The power of the scheme is proportional to the flow and to the head adapted to unexpected increases in electricity demand.



A 5-unit infrasound floating fence at a hydropower plant on the Gave de Pau River

Source: ProFish Technology

- 1 GWh supplies electricity for about 220 European households
- One small hydropower plant of 1 MW produces on average 5 GWh/year in Austria, supplying electricity to 1100 households
- 5 GWh/year supplies electricity to 2200 households in a developing country

> *On average, the range of investment costs varies in the range of EUR 1,000-3,000/kW*

The basic principle of hydropower is to transform the potential energy of water into mechanical energy available at a turbine shaft and afterwards into electricity through a generator. Water can be piped from a certain level to a lower level. If the water is allowed to move a mechanical component, then that movement involves conversion of the mechanical energy of the water into mechanical energy of this component. Hydro turbines convert water pressure and kinetic energy into mechanical energy, which can be used to drive an electricity generator. The main requirement is to have a 'head' so that water, diverted through an intake channel or a pipe (the penstock) into a turbine, discharges back into the river downstream. Sometimes the river has a suitable drop in level and the head is geologically given and available. In other cases, it is necessary to create an artificial head. The head is the difference in altitude between the water intake and the lower water level. It is normal to achieve optimum energy conversion efficiencies with all types of hydraulic turbines in the range of 80 up to over 90 per cent.

Various types of turbines exist to cope with different levels of head and flow. The two broad categories are: Impulse turbines - notably the Pelton, Turgo or the Banki-Michell (cross-flow) - in which water impinges or enters the runner, which is designed to change the water's direction and thereby extract the momentum from it with scarce change of pressure energy. Reaction turbines - notably Francis and Kaplan - which run full of water and in effect, generate hydrodynamic 'lift' forces to propel the runner blades, extracting thus the pressure energy of inflowing water. Generators transform mechanical energy into electrical energy.
An electric generator is made up of a stationary part (stator) and a moving part (rotor). The electric current is generated by the rotation of the magnetic field of the rotor through the coil of the conducting wiring of the stator. Once set in motion, the turbine drives the electric generator (either directly or through a multiplier), which then transforms the mechanical energy from the shaft into electrical energy. There are two categories of generators: the synchronous generators and the asynchronous (induction) generators. Asynchronous motors in generating mode are commonly used as generators in micro power plants. In order to use the electricity produced by the SHP plant it should be transmitted to the final user. The energy transformer allows electricity to be efficiently transmitted over long distances. This makes it possible to supply electricity to homes and businesses located far from the electric generating plant. The transformer is a device through which electromagnetic induction transforms alternating electric energy in one circuit into energy of a similar type in another circuit, commonly with altered values of voltage and current. The transformer situated inside the powerhouse takes

the alternating electric current from the generator terminals and converts it.

Power travels from the power plant to the end user through the power distribution grid. Because of the European effort for the development of renewable energy sources, utilities have received a large increase in demand for the connection of decentralised plants. The European policy framework supports easy access to the grid for renewable energy producers. SHP systems can also be stand-alone installations, i.e. not connected to the grid. Stand-alone micro-hydro does not need to have a battery bank. The frequency of the electricity is controlled using a load controller. However, a stand-alone scheme can be used to charge a battery bank, if this energy service is required. Off-grid small hydropower schemes are a suitable solution for electricity supply in developing countries, and in mountainous areas in developed ones. State-of-the-art industrial automation components and excellent communication features ensure that an operator can identify the status of the plant at anytime and anywhere, using computers, PDAs, cell phones or just a simple telephone and allows remote responses on problems where applicable.

The final implementation of a SHP plant is the result of a complex and interactive process, where consideration is given to both environmental impacts and different technological options as assessed from the economic point of view.

List of the studies that should be undertaken before implementation

- Topography and geomorphology of the site
- Evaluation of the water resource and its generating potential
- Site selection and basic layout
- Hydraulic turbines and generators and their control
- Environmental impact assessment and mitigation measures
- Economic evaluation of the project and financing potential
- Institutional framework and administrative procedures to attain the authorisations

Investment in a small hydropower scheme entails a certain number of expenses extended over the project lifetime and produces at the same time revenues also distributed over the same period. The expenses include a fixed component - the capital cost, insurance, taxes, etc and a variable component - operation and maintenance costs.

Feasibility studies

Feasibility studies include hydrological and environmental assessment, preliminary designs, permits and approvals (for water, land use and construction), land rights, interconnection studies, power purchase agreements (PPA), project management and financing fees. The cost of required permits varies from country to country with an average from EUR 10,000 to 30,000 for a request of authorisation. This amount is lost if the authorisation is denied. Grid interconnection studies as well as the relevant contracts for interconnection, transmission of energy through the power grid and power sales themselves (PPA) are of course fundamental for the success of a grid-connected plant.

Construction

The amount to invest varies from project to project. On average, the range of investment costs varies in the range of EUR 1,000-3,000/kW. The financial investment is recovered in 10 to 20 years without public financial assistance.

The revenues come from specific purchase contracts signed with the electric utilities. Depending on the legislation, electric utilities are usually obliged to buy the electricity generated from renewable energy resources on a priority basis. In some countries, there are specific incentives given to investment in electricity production using RES. According to these special schemes, renewable energy projects can apply for special loans with low or even zero interest rates, or receive other types of investment subsidies.

Prices paid to SHP producers vary considerably among European countries. In the tariff structure, different components can be found according to the country: a market price, an avoided carbon price, a green certificate price. The different support schemes can greatly affect the development of SHP. Whereas a fixed feed-in tariff reduces uncertainty and guarantees cash flow for a determined duration, market-based schemes can sometimes seem too uncertain and therefore unattractive to developers.

Applications: What's new?

The most recent areas of research in new technology and new orientations for the development of research and applications of SHP have been focused in the following areas:

- Reducing costs
- Reducing environmental impacts
- Increasing competitive performance
- Increasing efficiency
- Increasing innovation

The following will give some examples of how the different challenges have been addressed in the past years:

Recent EU projects funding the development of SHP technological research and applications

Shapes

ESHA is currently coordinating a partly EU funded project under the FP6 programme supported by DG-TREN in the European Commission. This project started in December 2007 and it will run until December 2009. It involves many partners from different countries such as Spain (ACCIONA), Lithuania (WMF), Switzerland (MHyLab), Austria (IWHW & WT), Italy (Studio Frosio), UK (DULAS), Poland (IMP PAN) and India (TERI). The overall objective of the project is to facilitate and strengthen the cooperation between the EU SHP Research and Market actors aiming at streamlining future research & development and promote R&D results in order to enhance penetration of SHP and know-how within the EU and on new markets in developing countries. The working areas of SHAPES focus on:

(a) the creation of a network of SHP actors and entities with the final goal of drafting an EU Research Agenda identifying the needs and gaps for the sector
(b) training of SHP specialists with the creation of specific educational basis and training for SHP experts
(c) promotion of SHP refurbishing with the production of a guide on how to refurbish SHP plants
(d) promotion of new technological solutions such as integration of SHP schemes in existing infrastructures, the identification and development of multipurpose plants and the combination with other technologies like ocean and wind energy

Detailed information on the project and the different actions can be found at www.esha.be/SHAPES

Hydroaction

ESHA is a partner in a HydroAction project (coordinated by National Technical University of Athens in Greece) which is an EU-funded FP7 research project that started recently. This project seeks to improve the productivity of small hydro turbines by developing a methodology for a low-cost design-optimisation of tailor-made small hydro turbines (up to five megawatts). The methodology will be validated with three turbine types: Pelton, Turgo and Matrix. The key optimisation target will be the increase of turbine productivity by increasing efficiency and operation range by three to five per cent together with the reduction of manufacturing costs.

The increase of efficiency of any energy transforming machine is of great importance as it corresponds to the reduction of fossil fuel consumption, which, especially for Europe, is entirely imported and the reduction of greenhouse gas emissions. The increase of efficiency of the hydraulic turbo-machines results in;

- The increase of electrical energy produced by renewable energy
- The saving of fossil fuel consumption and reduction of exhaust gas emissions
- The production of more efficient and competitive hydraulic turbines for the world market increases the competitiveness of European companies and helps maintain the industry leadership in the European Union

The project will run for three years. More information available at www.hydroaction.org

Fish friendly technologies (Pro-fish Technology & VLH eel-friendly turbine)

European industry and research institutes have tried to respond to growing environmental requirements with innovative solutions in bringing fish friendly technologies and turbines to the market. This is much needed since the EU Water Framework Directive requires free migration for fish on all water courses by 2015. Moreover, a recent regulation has been voted by the European Union to protect European eel stocks.

During their life cycle, some fish species (Atlantic salmon, European eel) undertake yearly downstream migration towards the sea. During this downstream migration, fish can encounter obstacles such as hydroelectric turbines.
In collaboration with the University of Liège, (Laboratory of Fish Demography, Belgium) and the University of Oslo (Norway), ProFish Technology has developed a new system based on infrasound emissions. This infrasound loudspeaker system is particularly efficient in deflecting fish away from industrial water intakes. Among the different natural acoustic signals encountered in water, low frequency sounds or infrasounds are picked up by all fish species. As fish swim, they naturally produce infrasounds. It has been scientifically demonstrated that infrasounds can deflect fish with efficiency close to 90 per cent on all species tested. The technology therefore demonstrates potential as an efficient multi-species fish repulsion system that can be widely applied.

By equipping water intakes with one or more infrasound units (depending on the size of the water intake), migrating fish are kept away from the intake area. At water intake areas on hydroelectric systems, the deterred fish can be guided towards bypasses and spillways. Currently, the ProFish Technology focuses their research activities on guidance systems for the silver eel.

Other fish friendly innovations include the 'eel-friendly' VLH-turbine and the University of

Southampton is making simulations on the impact of differential velocity or coverage in the fish passage and impact of fish behaviour.

Energy storage and combination with other RES

Hydroelectric generation can also be affected by the reduction of water resources. Technology has adapted practical solutions to produce hydroelectric energy even when countries are suffering from scarcity or drought. Pumped storage hydroelectric plants store energy in the form of water pumped from a lower reservoir to a higher one. At night, during low demand for electricity, the turbines run in reverse to pump water uphill from the higher reservoir. During periods of peak demand, water is released to generate electricity.

Wind energy can be coupled with hydropower plants for pumping water processes, as in the El Hierro Hydropower plant, a new and innovative technology for the first inland in the world with only renewable energies. In order to guarantee a constant energy supply, it was planned to accumulate wind energy that offers a huge potential in the inland, but that fluctuates as well by using a hydropower system composed of two reservoirs at different levels (high and low). When the production of wind energy is higher than the demand, water will be pumped to the high reservoir so that when the wind is not producing enough, the water storage in the high reservoir will be released to the low reservoir, allowing the movement of the turbines and therefore generating electricity. The wind installations represent 10 MW and the hydropower plant 10 MW, with two reservoirs of 700 metres head. This project is planned to be operational by 2010.

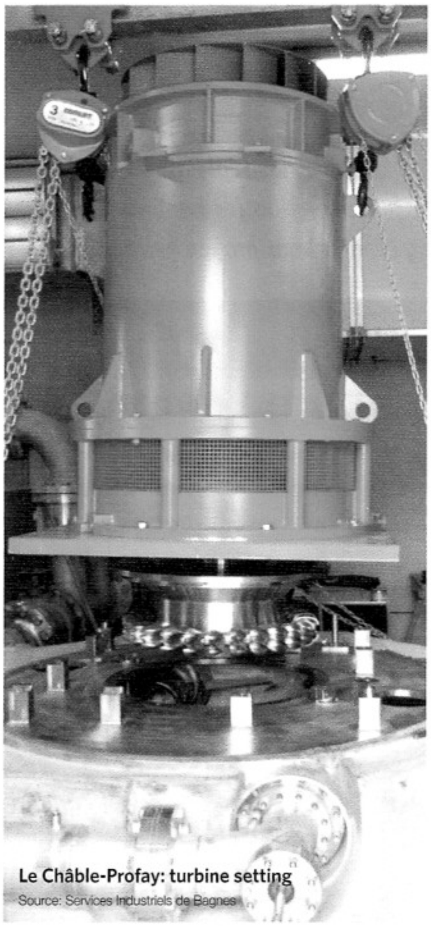
Low head

The VLH concept

The VLH concept was designed by hydro specialists to address a specific segment of the hydroelectric market, the very low head sites. This segment was only recently covered by the turbine manufacturers. Low-head hydro has the potential to generate green energy with only a minimal impact on the environment and it is one of the best options for decentralised power generation.

Traditionally, the R&D efforts of large turbine manufacturers have focused on the reduction of the turbine runner diameter in order to reduce the equipment costs while maintaining high turbine performance. This has been successful as there are efficient, high speed turbines with a small runner diameter on the market. However, in the case of the very low head small turbines, which are scaled down from large turbine technology, the costs are too high. This is because the associated inlet and outlet concrete work requires conveying the water from the intake to the runner and to recover the kinetic energy at the runner exit.

The VLH Turbine is designed specifically for very low sites (1.4 to 3.2 metres net head). The objective was to develop a unit that would require



Le Châble-Profay: turbine setting
Source: Services Industriels de Bagnes

very little civil work, would be easy to install and would offer a high degree of reliability at a reasonable cost per installed kW. The basic idea of the VLH concept is to decrease as much as possible the intake and outlet structures by increasing the size of the turbine runner diameter and by integrating a self-supporting structure, which ensures all the functions of a conventional facility.

The technical features of the VLH turbine concept make it a fish friendly turbine which allows downstream fish migration through the turbine runner itself. It has also achieved good results in eel friendliness tests. Therefore, with the growing concerns about the environment and the interest for distributed energy production, the development of low-head hydro sites fills the gap.

Currently, new features are under a R&D process in order to develop special applications of the VLH concept, such as multi groups for big rivers, navigation locks, water level regulation during floods, reinforced protection and withdrawing structure.

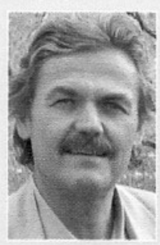
Conclusion

With today's increased need for clean energy and climate change mitigation, together with the requirements of the new RES Directive, there are pressures on governments to check their energy mix plans for the future. Regarding small hydropower, this does not mean only checking how much potential is left, but also in refurbishing and upgrading old sites and in developing multipurpose schemes.

The key challenges with small hydropower relate to both economics and ecology. Small hydropower can be successfully developed, as long as it produces electricity at competitive prices and under conditions that respect the environment. In order to increase the profitability of small hydropower, either the sale price must be increased or production costs must be reduced. Whereas the first is a political option, the second depends essentially on the technology. Reducing production costs implies firstly reducing construction, operation and maintenance costs, and secondly, institutional support is needed for further research and development.

It is essential to have well-structured and coordinated R&D programmes in order to continue and increase the development of new machines and construction techniques, with the objective that equipment and new and old plants are environment-friendly, simple, reliable and efficient, in other words to help the technology to become even more environmentally sustainable. Investment in R&D is also important in order to develop and boost innovative SHP solutions.

In the future, increased investment in R&D activities is a crucial aspect in order to boost clean energy in Europe and use SHP potential in the most environmentally-friendly and sustainable way!



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