Electricity production from hydropower has been, and still is today, the first renewable source used to generate electricity. Hydropower electricity in the European Union, both large and small scale, represents 13% of the total electricity generated, reducing the CO2 emissions by more than 67-million tons a year. Whereas conventional hydro requires flooding of large areas of land, with consequential environmental and social issues, properly designed small hydro schemes are easily integrated into local ecosystems.

In 2001, approximately 365 TWh of hydro energy was produced in the European Union from an overall capacity of 118 GW. Small hydro plants accounted for 8.4% of installed capacity (9.9 GW) and produced 39 TWh (about 11%). Given a more favorable regulatory environment, the European Commission objective of 14 000 MW by 2010 should be achievable and small hydro could be the second largest contributor behind windpower.

The large majority of small hydro plants are “run-of-river” schemes, meaning that they have no or relatively small water storage capability. The turbine only produces power when the water is available and provided by the river. When the river flow falls below some predetermined value, generation ceases.

Some plants are stand alone systems used in isolated sites, but in most cases, the electricity generated is connected to the grid. Stand-alone, small, independent schemes may not always be able to supply energy, unless their size is such that they can operate whatever the flow in the river is. In some cases, this problem can be overcome by using any existing lakes or reservoir storage that exists upstream of the plant. Connection to the grid has the advantage of easier control of system frequency, but has the disadvantage of being tripped off the system due to problems outside of the plant operator’s control.

It is possible for grid connected systems to sell either all or some of their energy to the supply company. However, the price paid for this energy is generally, in Europe particularly, fairly low. In recent years, supported by the RES-e directive, and in some cases national government legislation, enhanced payments are available for trading renewable energy. This has helped small scale developments obtain a reasonable rate of return on investment. It has also led to an increase in small scale hydro schemes being developed.

**Definition of small hydropower plant**

For the purposes of this text any scheme with an installed capacity of 10 MW or less will be considered as small. This figure is adopted by five member states, ESHA, the European Commission and UNIFEDE (International Union of Producers and Distributors of Electricity).

**Site configurations**

The objective of a hydropower scheme is to convert the potential energy of a mass of water, flowing with a certain fall to the turbine (termed the “head”), into electric energy at the lower end of the scheme, where the powerhouse is located. The power output from the scheme is proportional to the flow and to the head. Schemes are generally classified according to the “head”:

- **High head**: 100 m and above
- **Medium head**: 30 to 100 m
- **Low head**: 2 to 30 m

These ranges are not rigid but are merely a means of categorising sites.
Schemes can also be defined as:
- Run-of-river schemes
- Schemes with the powerhouse located at the base of a dam
- Schemes integrated on a canal or in a water supply pipe

**Run-of-river schemes**

Run-of-river schemes are where the turbine generates electricity as and when the water is available and provided by the river. When the river dries up and the flow falls below some predetermined amount or the minimum technical flow for the turbine, generation ceases.

Medium and high head schemes use weirs to divert water to the intake, from where it is then conveyed to the turbines via a pressure pipe or penstock. Penstocks are expensive and consequently this design is usually uneconomic. An alternative (Fig. 1) is to convey the water by a low-slope canal, running alongside the river to the pressure intake or forebay and then in a short penstock to the turbines. If the topography and morphology of the terrain does not permit the easy layout of a canal a low pressure pipe can be an economical option. At the outlet of the turbines, the water is discharged to the river via a tailrace.

Occasionally a small reservoir, storing enough water to operate only on peak hours, when prices for electricity are higher, can be created by the weir, or a similarly sized pond can be built in the forebay.

Low head schemes are typically built in river valleys. Two technological options can be selected. Either the water is diverted to a power intake with a short penstock (Fig. 2), as in the high head schemes, or the head is created by a small dam, provided with sector gates and an integrated intake (Fig. 3), powerhouse and fish ladder.

**Schemes with the powerhouse at the base of a dam**

A small hydropower scheme cannot afford a large reservoir to operate the plant when it is most convenient, the cost of a relatively large dam and its hydraulic appurtenances would be too high to make it economically viable. But if the reservoir has already been built for other purposes, such as flood control, irrigation, water abstraction for a big city, recreation area, etc – it may be possible to generate electricity using the discharge compatible with its fundamental use or the ecological flow of the reservoir. The main issue is how to link headwater and tail water by a waterway and how to fit the turbine in this waterway. If the dam already has a bottom outlet, see Fig. 4, for a possible solution.

Provided the dam is not too high, a siphon intake can be installed. Integral siphon intakes (Fig. 5) provide an elegant solution in schemes, generally, with heads up to 10 m and for units up to about...
1000 kW, although there are examples of siphon intakes with an installed power up to 11 MW (Sweden) and heads up to 30.5 m (USA). The turbine can be located either on top of the dam or on the downstream side. The unit can be delivered pre-packaged from the works, and installed without major modifications to the dam.

Schemes integrated within an irrigation canal
Two types of schemes can be designed to exploit irrigation canals:

Enlarged canal
The canal is enlarged to accommodate the intake, the power station, the tailrace and the lateral bypass. Fig. 6 shows a scheme of this kind, with a submerged powerhouse equipped with a right angle drive Kaplan turbine. To safeguard the water supply for irrigation, the scheme should include a lateral bypass, as in the figure, in case of shutdown of the turbine. This kind of scheme must be designed at the same time as the canal, as additional works whilst the canal is in full operation can be a very expensive option.

Existing canal
If the canal already exists, a scheme like the one shown in Fig. 7 is a suitable option.

The canal should be slightly enlarged to include the intake and the spillway. To reduce the width of the intake to a minimum, an elongated spillway should be installed. From the intake, a penstock running along the canal brings the water under pressure to the turbine. The water passes through the turbine and is returned to the river via a short tailrace.

Schemes integrated in a water abstraction system
The drinking water is supplied to a city by conveying the water from a headwater reservoir via a pressure pipe. Usually in this type of installation, the dissipation of energy at the lower end of the pipe at the entrance to the water treatment plant is achieved through the use of special valves. The fitting of a turbine at the end of the pipe, to convert this otherwise lost energy to electricity, is an attractive option, provided that the water hammer phenomenon is avoided. Water hammer overpressures are especially critical when the turbine is fitted on an old pressure pipe.

To ensure the water supply at all times, a system of bypass valves should be installed. In some water supply systems the turbine discharges to an open-air pond. The control system maintains the level of the pond. In case mechanical shutdown or turbine failure, the bypass valve system can also maintain the level of the pond.

Occasionally if the main bypass valve is out-of-operation and overpressure occurs, an ancillary bypass valve is rapidly opened by a counterweight. All the opening and closing of these valves must be slow enough to keep pressure variations within acceptable limits. The control system has to be more complex in those systems where the turbine outlet is subject to the counter-pressure of the network, as is shown in Fig. 8.

Planning a small hydropower scheme
The definitive project or scheme comes as the result of a complex and iterative process, where consideration is given to the environmental impact and different technological options. These are then costed and an economic evaluation carried out. Although it is not easy to provide a detailed guide on how to evaluate a scheme, it is possible to describe the fundamental steps to be followed, before deciding if one should proceed to a detailed feasibility study or not. Studies that should be undertaken include:
- 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.

Fig. 6: Integrated scheme using an irrigation canal.

Fig. 7: Elongated spillway scheme using an irrigation canal.

Fig. 8: Scheme integrated in a water supply system.
Environmental impact assessment and mitigation measures

Economic evaluation of the project and financing potential

Institutional framework and administrative procedures to attain the necessary consents

The water flowing along natural and man-made canals, conducted by low and high-pressure pipes, spilling over weir crests and moving the turbines involves the application of fundamental engineering principles in fluid mechanics.

To decide if a scheme will be viable it is necessary to begin by evaluating the water resource existing at the site. The energy potential of the scheme is proportional to the product of the flow and the head. Except for very low heads, the gross head can usually be considered as constant, but the flow varies over the year. To select the most appropriate hydraulic equipment and estimate the sites potential with calculations of the annual energy output, a flow-duration curve is most useful. A single measurement of instantaneous flow in a stream has little value.

Measuring the gross head requires a topographical survey. The results obtained by using a surveyor’s level and staff is accurate enough, but the recent advances in electronic surveying equipment make the topographical surveying work much simpler and faster. To produce a flow-duration curve on a gauged site is easier than producing a curve at an ungauged site. This requires a deeper understanding of hydrology.

An environmental impact assessment may be required to obtain the necessary consent to build the scheme and utilize the water available. Although several recent studies have shown that small hydropower produce no emissions to the atmosphere, nor do they produce toxic wastes or contribute to climatic change, designers should implement all necessary measures to mitigate local ecological impacts.

Further important considerations for the developer to take into account are trading tariffs for green and base energy and administrative procedures for grid connection. These depend on the energy policy and the institutional framework of each country.

Turbine selection criteria

The rated flow and net head determine the set of turbine types applicable to the site and the flow environment. Suitable turbines are those for which the given rated flow and net head plot within the operational envelopes (Fig. 9). A point defined as above by the flow and the head will usually plot within several of these envelopes. All of those turbines are appropriate for the job, and it will be necessary to compute installed power and electricity output against costs before making a decision. It should be remembered that the envelopes vary from manufacturer to manufacturer and they should be considered only as a guide.

As a turbine can only accept discharges between the maximal and the practical minimum, it may be advantageous to install several smaller turbines instead of one large turbine. The turbines would be sequentially started, so that all of the turbines in operation, except one, will operate at their nominal discharges and therefore will have a high efficiency. Using two or three smaller turbines will mean a lower unit weight and volume and will facilitate transport and assembly on the site. Sharing the flow between two or more units will also allow for higher rotational speed, which will reduce the need for a speed increaser.

The final choice between one or more units or between one type of turbine or another will be the result of an iterative calculation taking into account the investment costs and the yearly production.

Acknowledgement

This document is a summary of chapter 1 of an updated version of the “Layman’s guidebook on how to develop a small hydro site”, by Celso Penche, 1998, developed by the Thematic Network on Small hydropower (TNSHP), and is reprinted with permission.

The full document (Parts 1 and 2) may be downloaded from:


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