

CHAPTER 6: ELECTROMECHANICAL EQUIPMENT

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6 ELECTROMECHANICAL EQUIPMENT¹

This chapter gives the main description of the electromechanical equipment, some preliminary design rules and some selection criterion. For more technical description, please refer to L. Vivier², J. Raabe³ books and others publications^{4 5 6 7 8 9 10}.

6.1 Powerhouse

In a small hydropower scheme the role of the powerhouse is to protect the electromechanical equipment that convert the potential energy of water into electricity, from the weather hardships. The number, type and power of the turbo-generators, their configuration, the scheme head and the geomorphology of the site determine the shape and size of the building.

As shown in figures 6.1 and 6.2, the following equipment will be displayed in the powerhouse:

- Inlet gate or valve
- Turbine
- Speed increaser (if needed)
- Generator
- Control system
- Condenser, switchgear
- Protection systems
- DC emergency supply
- Power and current transformers
- etc.

Fig. 6.1 is a schematic view of an integral intake indoor powerhouse suitable for low head schemes. The substructure is part of the weir and embodies the power intake with its trashrack, the vertical axis Kaplan turbine coupled to the generator, the draft tube and the tailrace. The control equipment and the outlet transformers are located in the generator forebay.

In order to mitigate the environmental impact the powerhouse can be entirely submerged (see chapter 1, figure 1.6). In this way the level of sound is sensibly reduced and the visual impact is nil.

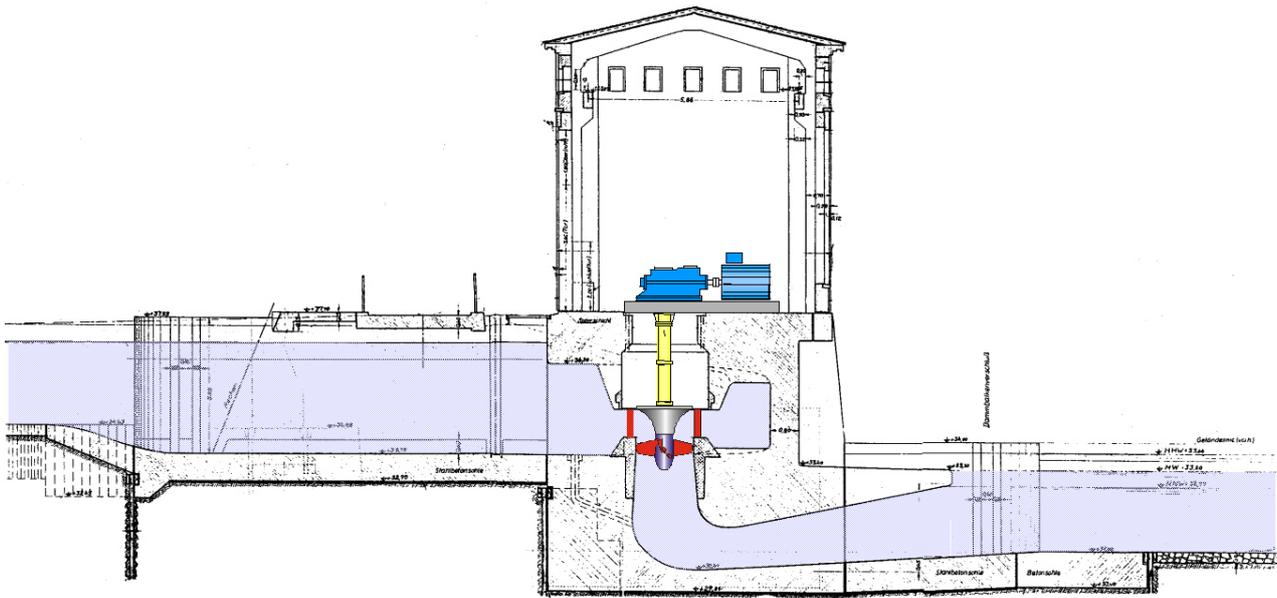


Figure 6.1: Schematic view of a powerhouse –Low head

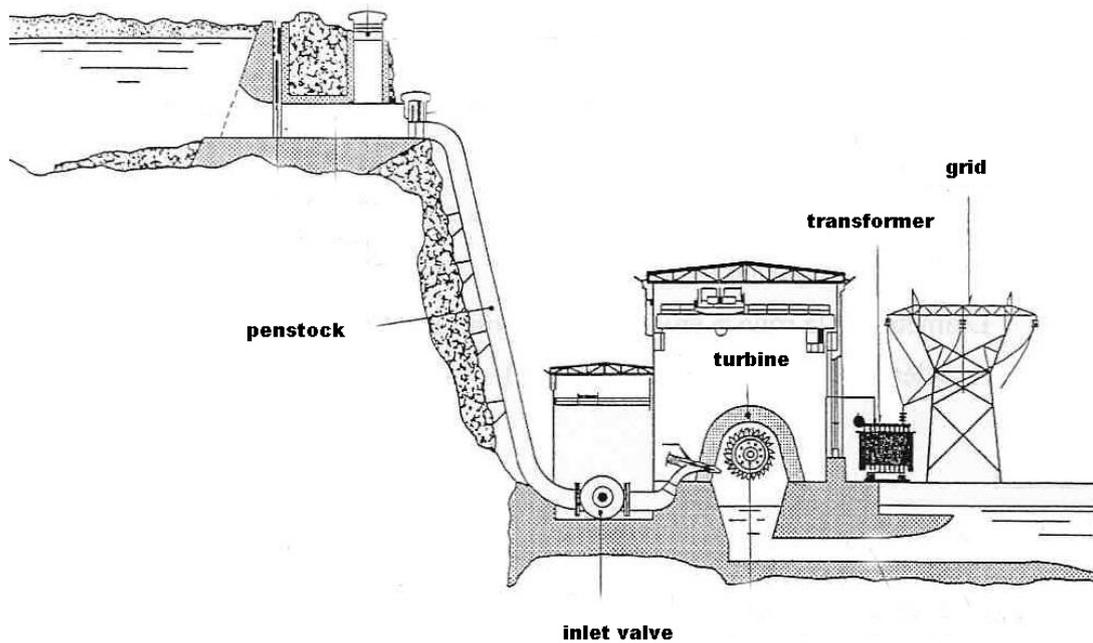


Figure 6.2: Schematic view of a powerhouse –high and medium heads

In medium and high head schemes, powerhouses are more conventional (see figure 6.2) with an entrance for the penstock and a tailrace. Although not usual, this kind of powerhouse can be underground.



Photo 6.1: Overview of a typical powerhouse

The powerhouse can also be at the base of an existing dam, where the water arrives via an existing bottom outlet or an intake tower. Figure 1.4 in chapter 1 illustrates such a configuration.

As we will see in chapter 6.1.1.2, some turbines configurations allow for the whole superstructure itself, to be dispensed with, or reduced enclosing only the switchgear and control equipment. Integrating the turbine and generator in a single waterproofed unit that can be installed directly in the waterway means that a conventional powerhouse is not required (bulb or siphon units).

6.2 Hydraulic turbines

The purpose of a hydraulic turbine is to transform the water potential energy to mechanical rotational energy. Although this handbook does not define guidelines for the design of turbines (a role reserved for the turbine manufacturers) it is appropriate to provide a few criteria to guide the choice of the right turbine for a particular application and even to provide appropriate formulae to determine its main dimensions. These criteria and formulae are based on work undertaken by Siervo and Lugaresi¹¹, Siervo and Leva^{12 13}, Lugaresi and Massa^{14 15}, Austerre and Verdehan¹⁶, Giraud and Beslin¹⁷, Belhaj¹⁸, Gordon^{19 20}, Schweiger and Gregori^{21 22} and others, which provide a series of formulae by analysing the characteristics of installed turbines. It is necessary to emphasize however that no advice is comparable to that provided by the manufacturer, and every developer should refer to manufacturer from the beginning of the development project.

All the formulae of this chapter use SI units and refer to IEC standards (IEC 60193 and 60041).

6.2.1 Types and configuration

The potential energy in water is converted into mechanical energy in the turbine, by one of two fundamental and basically different mechanisms:

- The water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. Turbines that operate in this way are called reaction turbines. The turbine casing, with the runner fully immersed in water, must be strong enough to withstand the operating pressure. Francis and Kaplan turbines belong to this category.

- The water pressure is converted into kinetic energy before entering the runner. The kinetic energy is in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Turbines that operate in this way are called impulse turbines. The most usual impulse turbine is the Pelton.

This chapter describes each turbine type, presented by decreasing head and increasing nominal flow. The higher the head, the smaller the flow.

The hydraulic power at disposition of the turbine is given by:

$$P_h = \rho Q \cdot gH \quad [W] \quad (6.1)$$

- Where:
- ρQ = mass flow rate [kg/s]
 - ρ = water specific density [kg/m³]
 - Q = Discharge [m³/s]
 - gH = specific hydraulic energy of machine [J/kg]
 - g = acceleration due to gravity [m/s²]
 - H = "net head" [m]

The mechanical output of the turbine is given by:

$$P_{mec} = P_h \cdot \eta \quad [W] \quad (6.2)$$

- η = turbine efficiency [-]

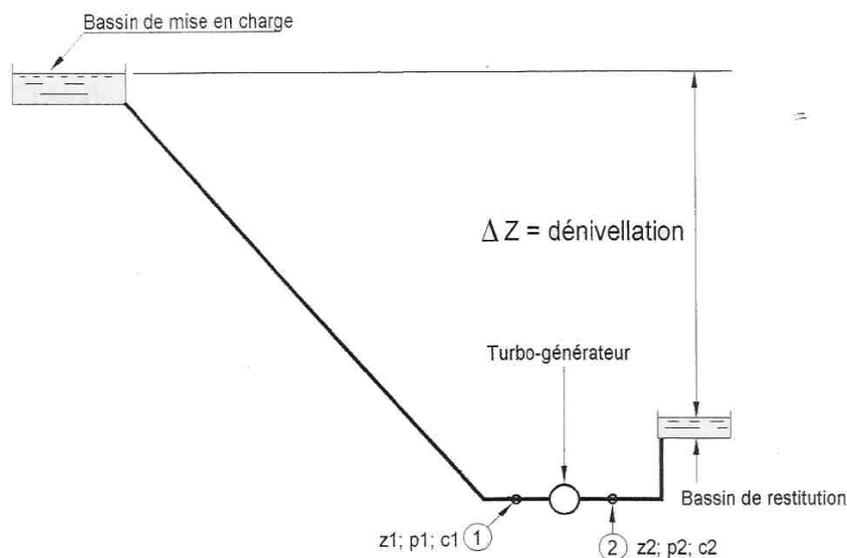


Figure 6.3: Schematic view of a hydropower scheme and of the measurement sections

The specific hydraulic energy of machine is defined as follows:

$$E = gH = \frac{1}{\rho} \cdot (p_1 - p_2) + \frac{1}{2} \cdot (c_1^2 - c_2^2) + g \cdot (z_1 - z_2) \quad [\text{m}] \quad (6.3)$$

- Where:
- gH = specific hydraulic energy of machine [J/kg]
 - p_x = pressure in section x [Pa]
 - c_x = water velocity in section x [m/s]
 - z_x = elevation of the section x [m]

The subscripts 1 and 2 define the upstream and downstream measurement section of the turbine. They are defined by IEC standards.

The net head is defined as:

$$H_n = \frac{E}{g} \quad [\text{m}] \quad (6.4)$$

Impulse turbines

Pelton turbines

Pelton turbines are impulse turbines where one or more jets impinge on a wheel carrying on its periphery a large number of buckets. Each jet issues water through a nozzle with a needle valve to control the flow (figure 6.4). They are only used for high heads from 60 m to more than 1 000 m. The axes of the nozzles are in the plan of the runner. In case of an emergency stop of the turbine (e.g. in case of load rejection), the jet may be diverted by a deflector so that it does not impinge on the buckets and the runner cannot reach runaway speed. In this way the needle valve can be closed very slowly, so that overpressure surge in the pipeline is kept to an acceptable level (max 1.15 static pressure).

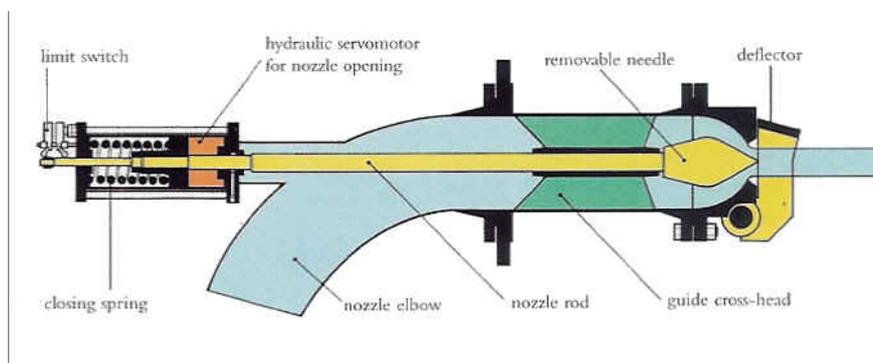


Figure 6.4: Cross section of a nozzle with deflector

As any kinetic energy leaving the runner is lost, the buckets are designed to keep exit velocities to a minimum.

One or two jet Pelton turbines can have horizontal or vertical axis, as shown in figure 6.5. Three or more nozzles turbines have vertical axis (see figure 6.6). The maximum number of nozzles is 6 (not usual in small hydro).

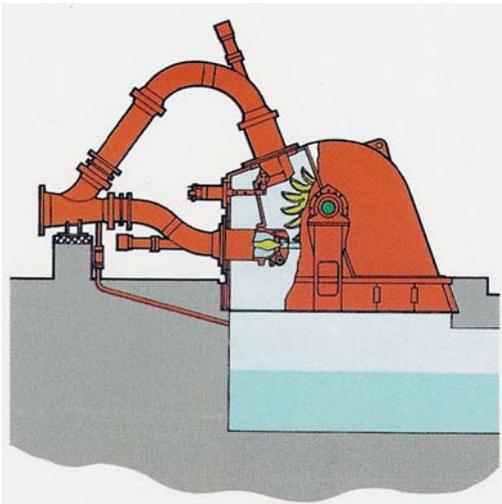


Figure 6.5: View of a two nozzles horizontal Pelton

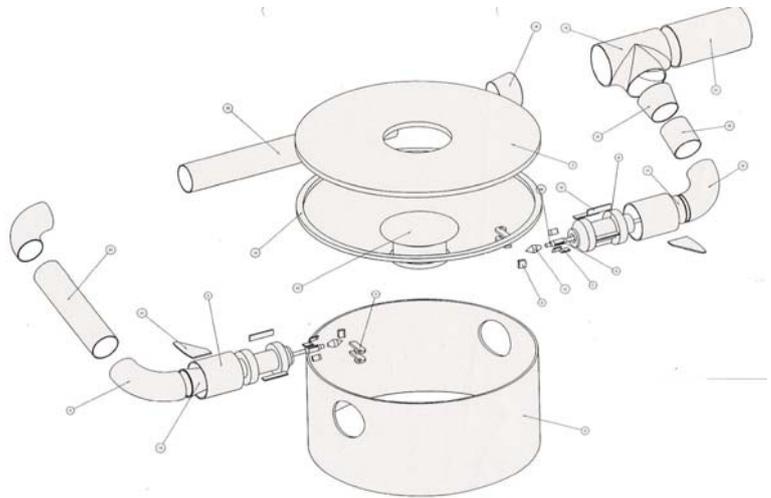


Figure 6.6: View of a two nozzle vertical Pelton

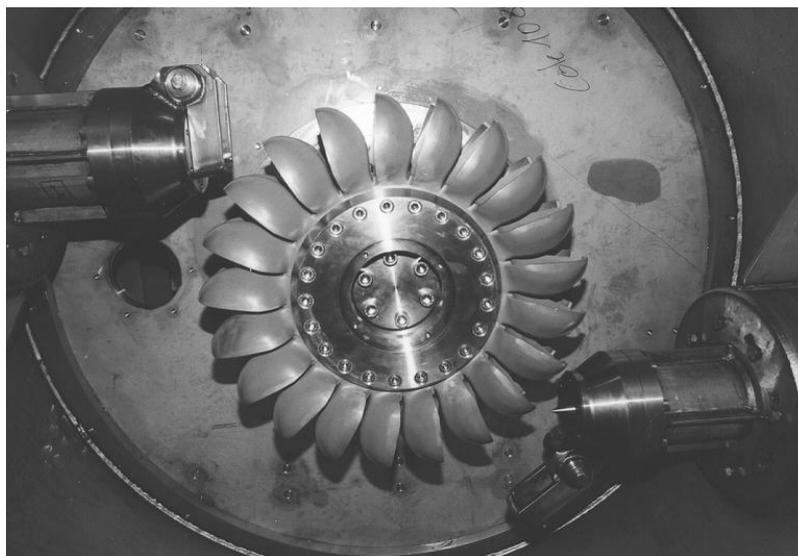


Photo 6.2: Pelton runner

The turbine runner is usually directly coupled to the generator shaft and shall be above the downstream level. The turbine manufacturer can only give the clearance.

The efficiency of a Pelton is good from 30% to 100% of the maximum discharge for a one-jet turbine and from 10% to 100% for a multi-jet one.

Turgo turbines

The Turgo turbine can operate under a head in the range of 50-250 m. Like the Pelton, it is an impulse turbine, however its buckets are shaped differently and the jet of water strikes the plane of its runner at an angle of 20°. Water enters the runner through one side of the runner disk and emerges from the other (Figure 6.7). It can operate between 20% and 100% of the maximal design flow.

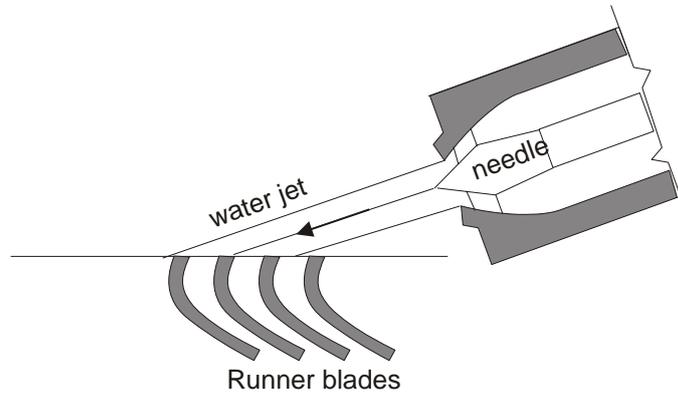


Figure 6.7: Principle of a Turgo turbine

The efficiency is lower than for the Pelton and Francis turbines.

Compared to the Pelton, a Turgo turbine has a higher rotational speed for the same flow and head.

A Turgo can be an alternative to the Francis when the flow strongly varies or in case of long penstocks, as the deflector allows avoidance of runaway speed in the case of load rejection and the resulting water hammer that can occur with a Francis.

Cross-flow turbines

This impulse turbine, also known as Banki-Michell is used for a wide range of heads overlapping those of Kaplan, Francis and Pelton. It can operate with heads between 5 and 200 m.

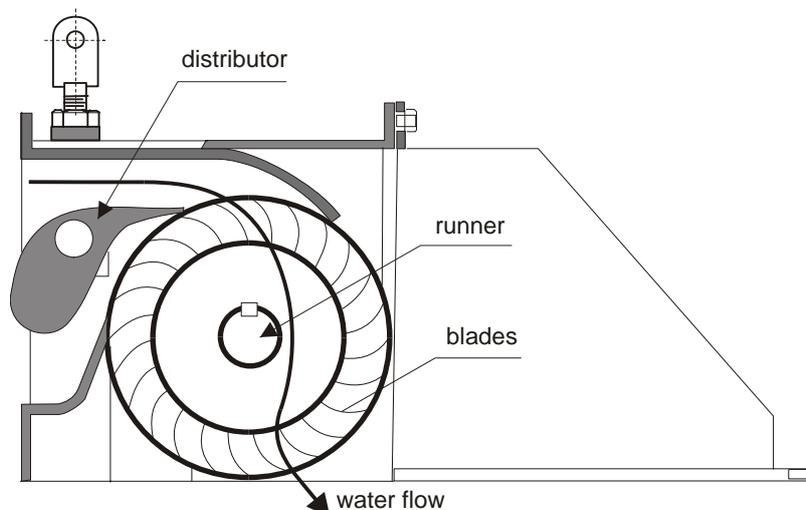


Figure 6.8: Principle of a Cross-flow turbine

Water (figure 6.8) enters the turbine, directed by one or more guide-vanes located upstream of the runner and crosses it two times before leaving the turbine.

This simple design makes it cheap and easy to repair in case of runner brakes due to the important mechanical stresses.

The Cross-flow turbines have low efficiency compared to other turbines and the important loss of head due to the clearance between the runner and the downstream level should be taken into consideration when dealing with low and medium heads. Moreover, high head cross-flow runners may have some troubles with reliability due to high mechanical stress.

It is an interesting alternative when one has enough water, defined power needs and low investment possibilities, such as for rural electrification programs.

Reaction turbines

Francis turbines.

Francis turbines are reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. In this turbine the admission is always radial but the outlet is axial. Photograph 6.3 shows a horizontal axis Francis turbine. Their usual field of application is from 25 to 350 m head.

As with Peltons, Francis turbines can have vertical or horizontal axis, this configuration being really common in small hydro.

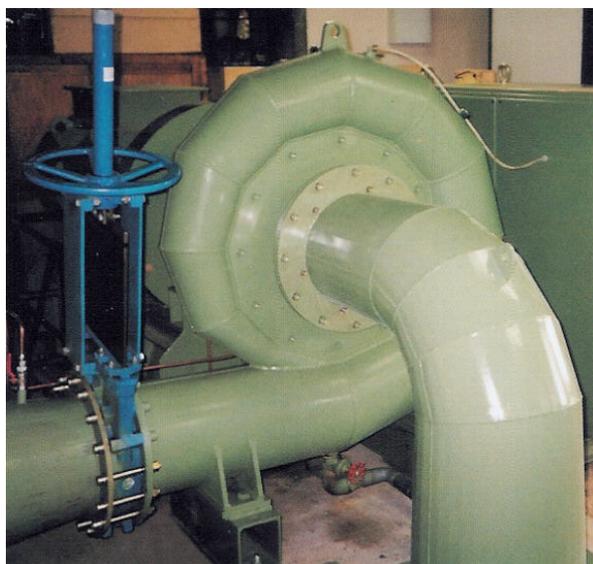


Photo 6.3: Horizontal axis Francis turbine

Francis turbines can be set in an open flume or attached to a penstock. For small heads and power open flumes were commonly employed, however nowadays the Kaplan turbine provides a better technical and economical solution in such power plants.

The water enters the turbine by the spiral case that is designed to keep its tangential velocity constant along the consecutive sections and to distribute it peripherally to the distributor. As shown in figure 6.9, this one has mobile guide vanes, whose function is to control the discharge going into the runner and adapt the inlet angle of the flow to the runner blades angles. They rotate around their axes by connecting rods attached to a large ring that synchronise the movement of all vanes. They can be used to shut off the flow to the turbine in emergency situations, although their use does not

preclude the installation of a butterfly valve at the entrance to the turbine. The runner transforms the hydraulic energy to mechanical energy and returns it axially to the draft tube.

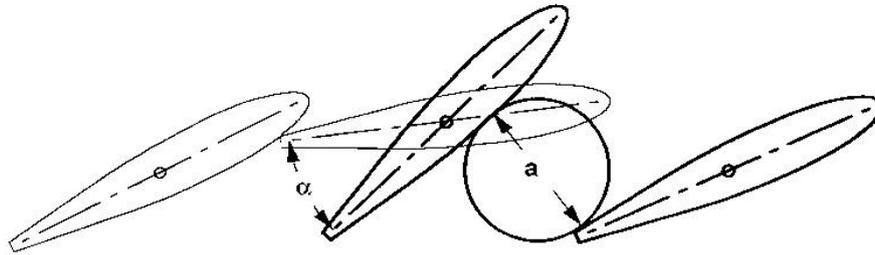


Figure 6.9: Guide vane functioning principle



Photo 6.4: Horizontal axis Francis turbine guide vane operating device



Photo 6.5: Francis runner

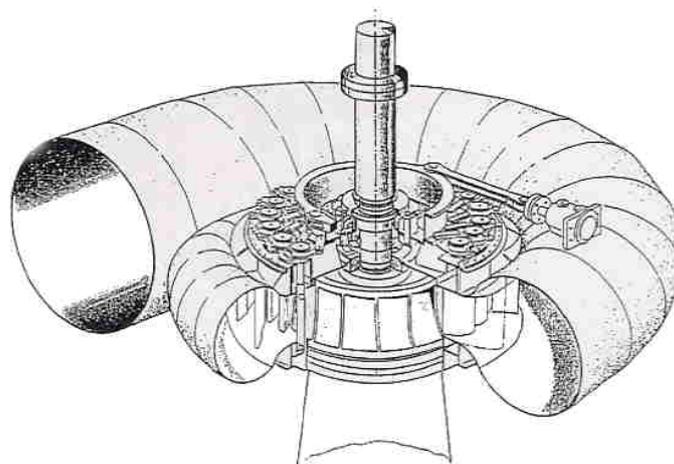


Figure 6.10: View of a Francis Turbine

Small hydro runners are usually made in stainless steel castings. Some manufacturers also use aluminium bronze casting or welded blades, which are generally directly coupled to the generator shaft.

The draft tube of a reaction turbine aims to recover the kinetic energy still remaining in the water leaving the runner. As this energy is proportional to the square of the velocity one of the draft tube objectives is to reduce the turbine outlet velocity. An efficient draft tube would have a conical section but the angle cannot be too large, otherwise flow separation will occur. The optimum angle is 7° but to reduce the draft tube length, and therefore its cost, sometimes angles are increased up to 15°.

The lower head, the more important the draft tube is. As low head generally implies a high nominal discharge, the remaining water speed at the outlet of the runner is quite important. One can easily understand that for a fixed runner diameter, the speed will increase if the flow does. Figure 6.11 shows the kinetic energy remaining at the runner outlet as a function of the specific speed (see chapter 6.1.2 for the definition of specific speed).

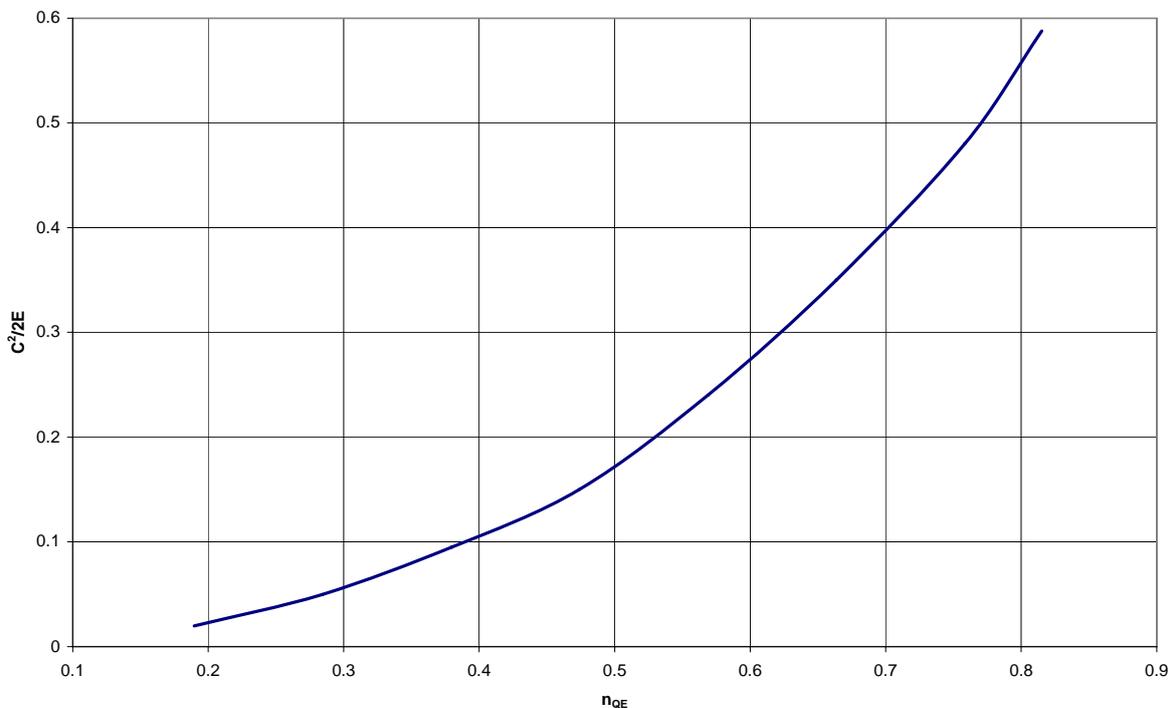


Figure 6.11: Kinetic energy remaining at the outlet of the runner.

Kaplan and propeller turbines

Kaplan and propeller turbines are axial-flow reaction turbines; generally used for low heads from 2 to 40 m. The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide- vanes. If both blades and guide-vanes are adjustable it is described as "double-regulated". If the guide-vanes are fixed it is "single-regulated". Fixed runner blade Kaplan turbines are called propeller turbines. They are used when both flow and head remain practically constant, which is a characteristic that makes them unusual in small hydropower schemes.

The double regulation allows, at any time, for the adaptation of the runner and guide vanes coupling to any head or discharge variation. It is the most flexible Kaplan turbine that can work between 15% and 100% of the maximum design discharge. Single regulated Kaplan allows a good adaptation to varying available flow but is less flexible in the case of important head variation. They can work between 30% and 100% of the maximum design discharge.



Photo 6.6: Kaplan runner

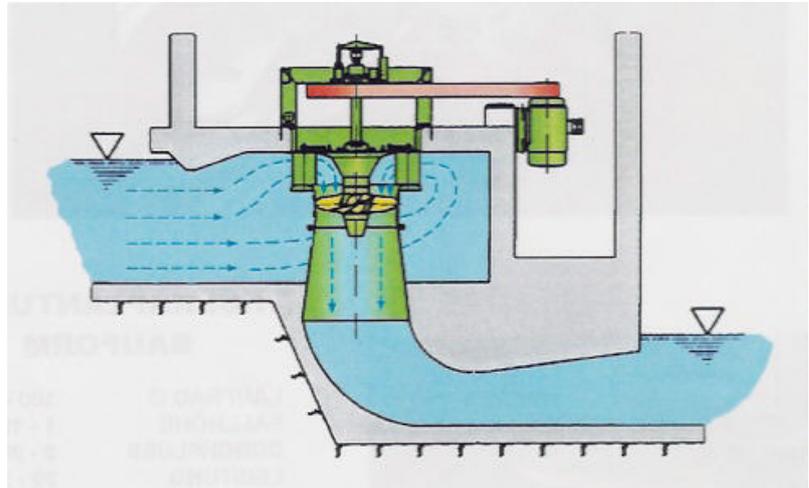


Figure 6.12: Cross section of a double regulated Kaplan turbine

The double-regulated Kaplan illustrated in figure 6.12 is a vertical axis machine with a spiral case and a radial guide vane configuration. The flow enters in a radial manner inward and makes a right angle turn before entering the runner in an axial direction. The control system is designed so that the variation in blade angle is coupled with the guide-vanes setting in order to obtain the best efficiency over a wide range of flows and heads. The blades can rotate with the turbine in operation, through links connected to a vertical rod sliding inside the hollow turbine axis.

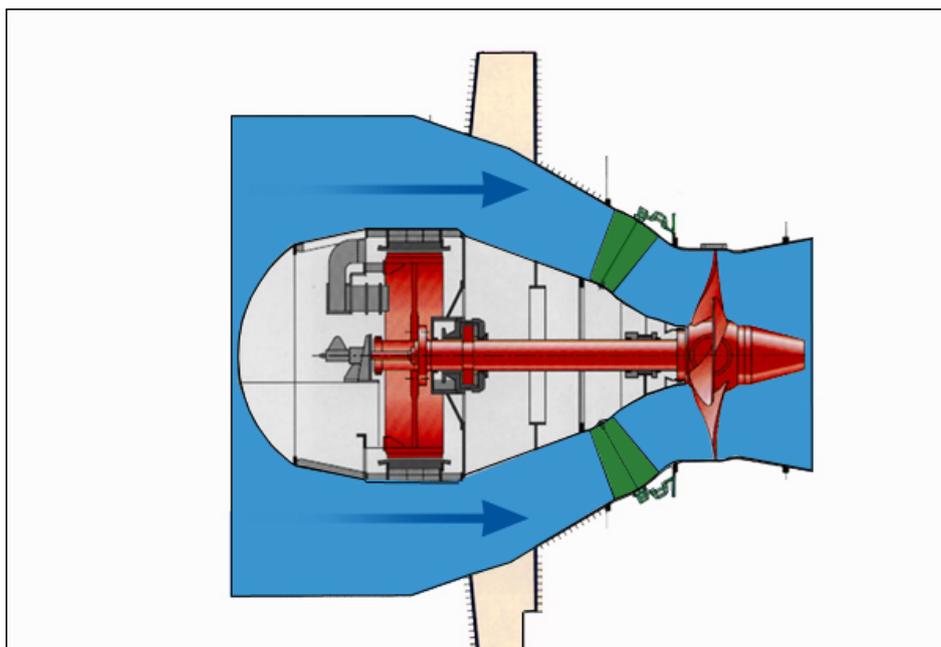


Figure 6.13: Cross section of a double regulated Bulb turbine

Bulb units are derived from Kaplan turbines, with the generator contained in a waterproofed bulb submerged in the flow. Figure 6.13 illustrates a turbine where the generator (and gearbox if required), cooled by pressurised air, is lodged in the bulb. Only the electric cables, duly protected, leave the bulb.

Kaplan turbines are certainly the machines that allow the most number of possible configurations. The selection is particularly critical in low-head schemes where, in order to be profitable, large discharges must be handled. When contemplating schemes with a head between 2 and 5 m, and a discharge between 10 and 100 m³/sec, runners with 1.6 - 3.2 metres diameter are required, coupled through a speed increaser to a generator. The hydraulic conduits in general, and water intakes in particular, are very large and require very large civil works with a cost that generally exceeds the cost of the electromechanical equipment.

In order to reduce the overall cost (civil works plus equipment) and more specifically the cost of the civil works, several configurations have been devised that nowadays are considered as classic.

The selection criteria for such turbines are well known:

- Range of discharges
- Net head
- Geomorphology of the terrain
- Environmental requirements (both visual and sonic)
- Labour cost

The configurations differ by how the flow goes through the turbine (axial, radial, or mixed), the turbine closing system (gate or siphon), and the speed increaser type (parallel gears, right angle drive, belt drive).

For those interested in low-head schemes please read the paper presented by J. Fonkenell to *HIDROENERGIA* 91²³ dealing with selection of configurations. Following table and figures show all the possible configurations.

Table 6.1: Kaplan turbines configuration

Configuration	Flow	Closing system	Speed increaser	Figure
Vertical Kaplan	Radial	Guide-vanes	Parallel	6.14
Vertical semi-Kaplan siphon	Radial	Siphon	Parallel	6.15
Inverse semi-Kaplan siphon	Radial	Siphon	Parallel	6.16
Inclined semi-Kaplan siphon	Axial	Siphon	Parallel	6.17
Kaplan S	Axial	Gate valve	Parallel	6.18
Kaplan inclined right angle	Axial	Gate valve	Conical	6.19
Semi-Kaplan in pit	Axial	Gate valve	Parallel	6.20

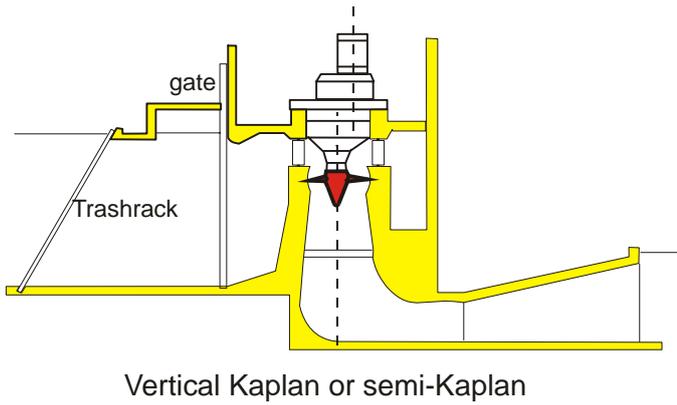


Figure 6.14: Cross section of a vertical Kaplan power plant

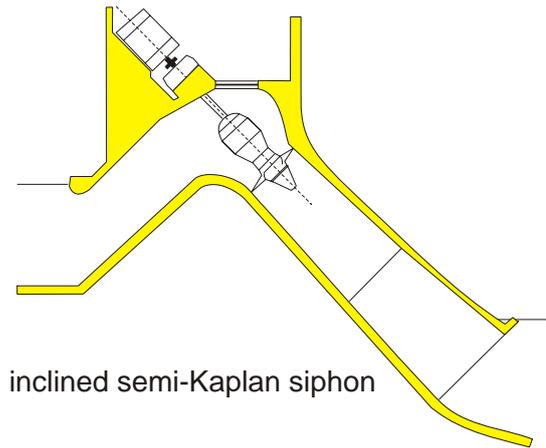


Figure 6.15: Cross section of a Kaplan siphon power plant

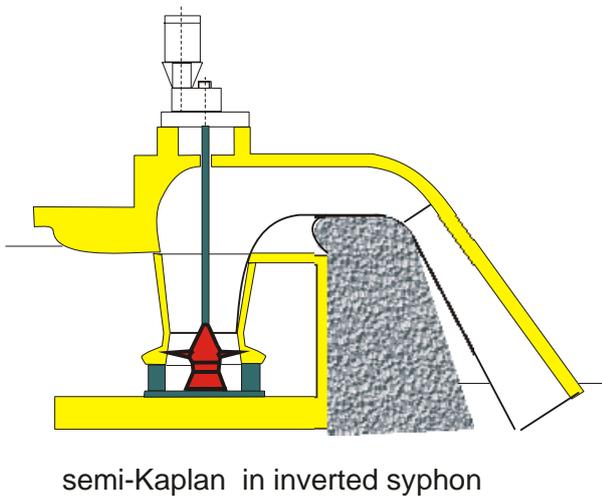


Figure 6.16: Cross section of a Kaplan inverse siphon power plant

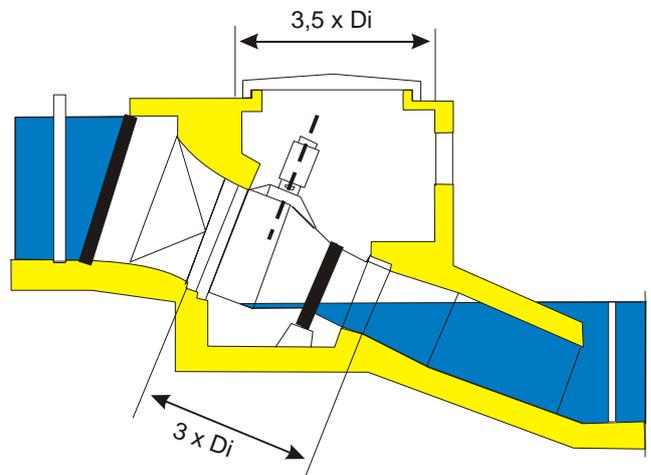


Figure 6.17: Cross section of an inclined Kaplan power plant

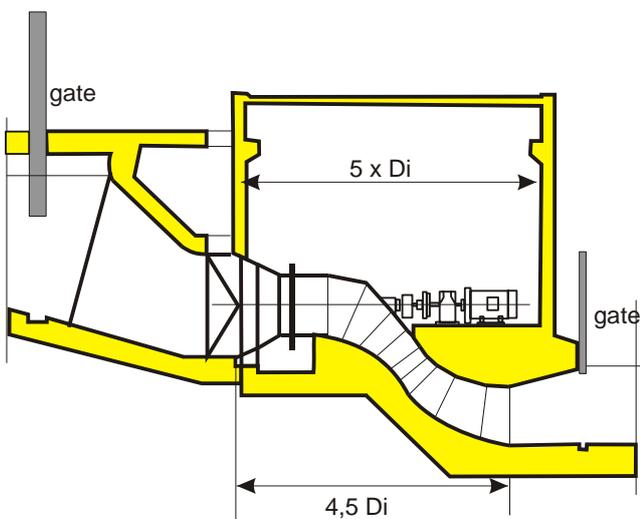


Figure 6.18: Cross section of a S Kaplan power plant

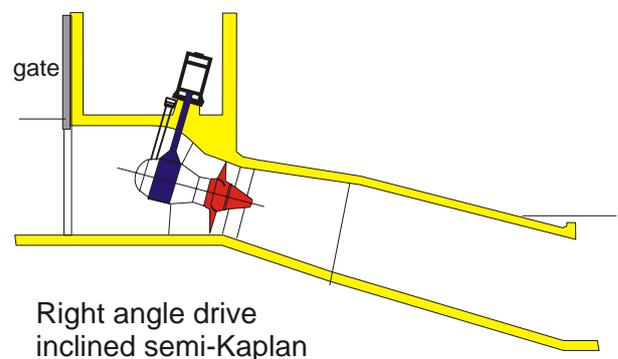


Figure 6.19: Cross section of an inclined right angle Kaplan power plant

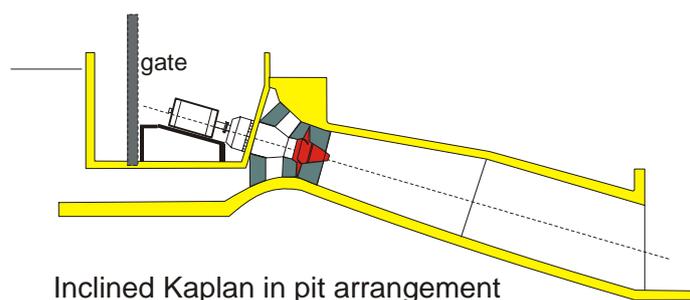


Figure 6.20: Cross section of a pit Kaplan power plant



Photo 6.7: Siphon Kaplan

Siphons are reliable, economic, and prevent runaway turbine speed, however they are noisy if no protection measures are taken to isolate the suction pump and valves during starting and stopping operations. Even if not required for normal operation, a closing gate is strongly recommended as it avoids the unintended starting of the turbine due to a strong variation of upstream and downstream levels. In case of such a problem, the turbine will reach high speeds and the operator will not have the means to stop it. A solution to this problem is the use of flap gate dams.

Underground powerhouses are best at mitigating the visual and sonic impact, but are only viable with an S, a right angle drive or a pit configuration.

The speed increaser configuration permits the use of a standard generator usually turning at 750 or 1 000 rpm, and is also reliable, compact and cheap. The S configuration is becoming very popular, however one disadvantage is that the turbine axis has to cross either the entrance or the outlet pipe with consequent head losses. It is mainly used for medium heads and/or hydropower schemes with penstock.

The pit configuration has the advantage of easy access to all the equipment components, in particular the coupling of turbine and speed increaser, the speed increaser itself and the generator, which facilitates inspection, maintenance and repair. This configuration is popular for very low heads and high discharges allowing a runner diameter bigger than 2 m.

For the same reasons as for the Francis turbines, Kaplans must have a draft tube. Due to the low heads, the kinetic energy is very important and the quality of this part of the turbine should not be neglected.

Figure 6.21 shows four different designs of runners and their corresponding specific speeds, optimised from the efficiency viewpoint. The lower the specific speed, the higher the corresponding head.

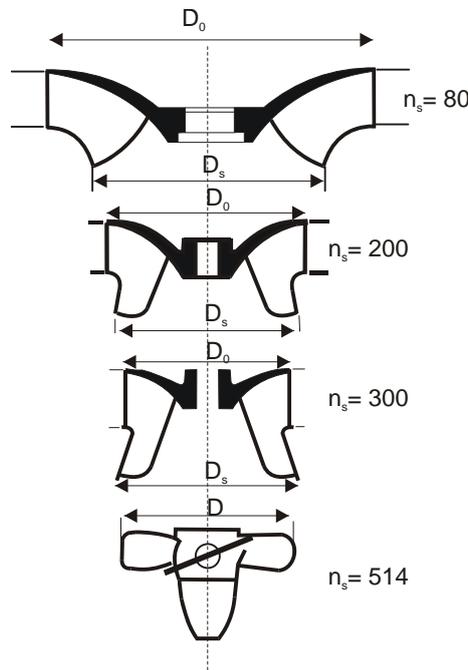


Figure 6.21: Design of turbine runners in function of the specific speed n_s

In general turbine manufacturers denote the specific speed of their turbines. A large number of statistical studies on a large number of schemes have established a correlation of the specific speed and the net head for each type of turbine. Some of the correlation formulae are graphically represented in figure 6.22.

Pelton (1 nozzle) $n_{QE} = \frac{0.0859}{H_n^{0.243}}$ (Siervo and Lugaresi) [-] (6.9)

Francis $n_{QE} = \frac{1.924}{H_n^{0.512}}$ (Lugaresi and Massa) [-] (6.10)

Kaplan $n_{QE} = \frac{2.294}{H_n^{0.486}}$ (Schweiger and Gregory) [-] (6.11)

Propeller $n_{QE} = \frac{2.716}{H_n^{0.5}}$ (USBR) [-] (6.12)

Bulb $n_{QE} = \frac{1.528}{H_n^{0.2837}}$ (Kpordze and Warnick) [-] (6.13)

Once the specific speed is known the fundamental dimensions of the turbine can be easily estimated. However, one should use these statistical formulae only for preliminary studies as only manufacturers can give the real dimensions of the turbines.

In Pelton turbines, the specific speed increases with the square root of the number of jets. Therefore the specific speed of a four jet Pelton (only exceptionally they do have more than four jets, and then only in vertical axis turbines) is twice the specific speed of one jet Pelton.

Table 6.2 shows the typical specific speed of the main turbines types.

Table 6.2: Range of specific speed for each turbine type

Pelton one nozzle	$0.005 \leq n_{QE} \leq 0.025$
Pelton n nozzles	$0.005 \cdot n^{0.5} \leq n_{QE} \leq 0.025 \cdot n^{0.5}$
Francis	$0.05 \leq n_{QE} \leq 0.33$
Kaplan, propellers, bulbs	$0.19 \leq n_{QE} \leq 1.55$

Figure 6.23 shows the specific speed evolution function of the net head and of the turbine type.

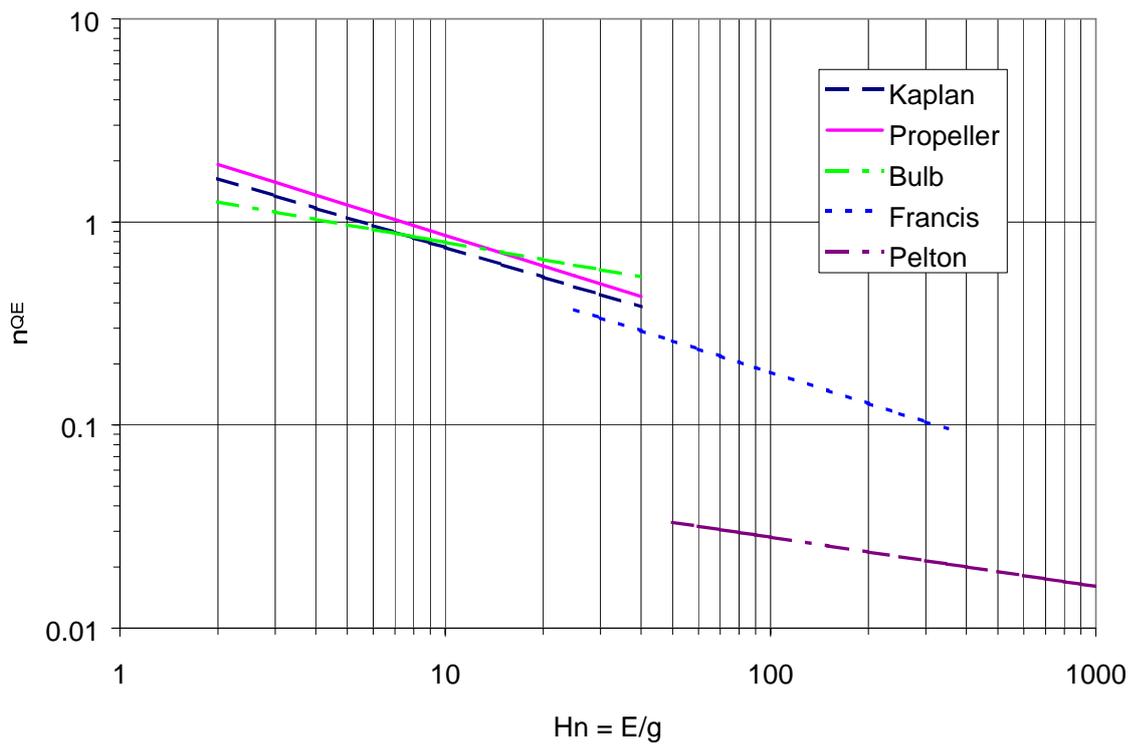


Figure 6.22: Specific speed in function of the net head $H_n = E/g$.

In addition, some basic similarity laws are given hereafter.

$$\frac{Q_t}{Q_m} = \frac{\sqrt{H_t} \cdot D_t^2}{\sqrt{H_m} \cdot D_m^2} \quad [-] \quad (6.14)$$

$$\frac{n_t}{n_m} = \frac{\sqrt{H_t}}{\sqrt{H_m}} \cdot \frac{D_m}{D_t} \quad [-] \quad (6.15)$$

Where t correspond to the industrial turbine and m to the laboratory model.

The following example illustrates the use of the similarity laws.

If we intend to build a model with a 1:5 scale of a turbine working with an 80 m net head at 10 m³/s and running at 750 rpm, then to test it under a net head of 10 m, the model discharge will be 0.141 m³/s and its rotational speed 1'326 rpm.

Another example is the case where a turbine would be designed for 120 net Head at 1 m³/s, and 750 rpm, but is now used under 100 m net head. In this case $D_t = D_m$. In order to work properly, the turbine should have a rotational speed of 685 rpm and the maximum admissible flow would be 0.913 m³/s.

6.2.3 Preliminary design

This chapter will give some statistical formulae allowing for the determination of the main dimensions of the turbine runner for Pelton, Francis and Kaplan turbines.

It has to be remembered that the turbine design is an iterative process depending on miscellaneous criterion as cavitation limits, rotational speed, specific speed, etc. (see chapter 6.1.4). Clearly, it means that after using the following equation, one has to control that the preliminary designed turbine complies with the above-mentioned criterion.

For all turbine types, the first step is to choose a rotational speed.

Pelton turbines

If we know the runner speed its diameter can be estimated by the following equations:

$$D_1 = 0.68 \cdot \frac{\sqrt{H_n}}{n} \quad [m] \quad (6.16)$$

$$B_2 = 1.68 \cdot \sqrt{\frac{Q}{n_{jet}} \cdot \frac{1}{\sqrt{H_n}}} \quad [m] \quad (6.17)$$

$$D_e = 1.178 \cdot \sqrt{\frac{Q}{n_{jet}} \cdot \frac{1}{\sqrt{gH}}} \quad [m] \quad (6.18)$$

Where n is the rotational speed in t/s and n_{jet} , the number of nozzles.

D_1 is defined as the diameter of the circle describing the buckets centre line. B_2 is the bucket width, mainly depending on the discharge and number of nozzles. D_e is the nozzle diameter.

As a general rule, the ratio D_1 / B_2 must always be greater than 2.7. If this is not the case, then a new calculation with a lower rotational speed or more nozzles has to be carried out.

The discharge function of the nozzle opening C_p - in one jet turbine the total discharge – can be estimated according to the following formulae:

$$Q_{jet} = K_v \cdot \pi \cdot \frac{D_e^2}{4} \cdot \sqrt{2 \cdot gH} \quad [m^3/s] \quad (6.19)$$

Where K_v is given in the figure 6.23 function of the relative opening $a = C_p/D_e$.

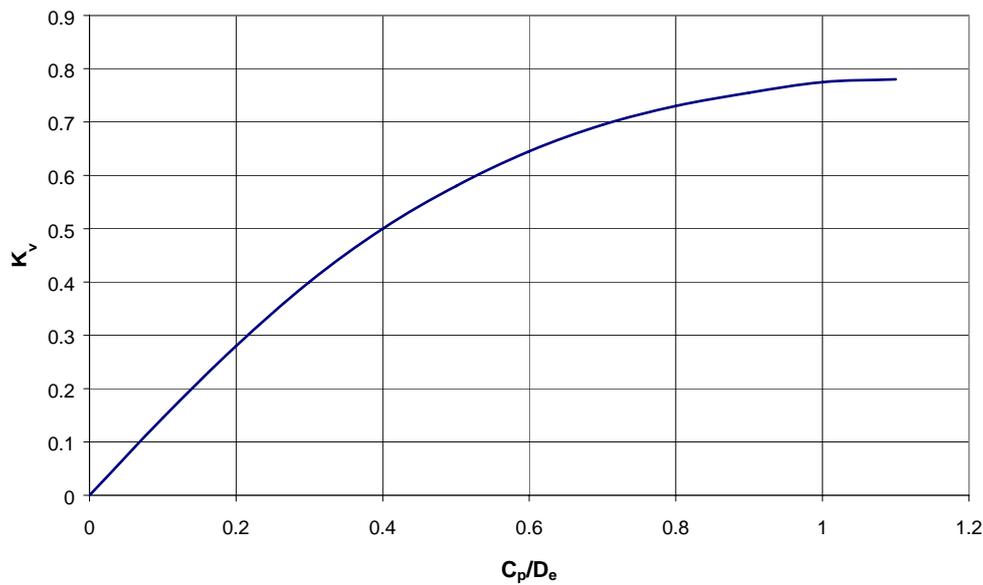


Figure 6.23: Nozzle characteristic

For the other dimension calculations, please refer to the De Siervo and Lugaresi article ¹⁰.

Francis turbines

Francis turbines cover a wide range of specific speeds, going from 0.05 to 0.33 corresponding to high head and low head Francis respectively.

Figure 6.24 shows schematically a cross section of a Francis runner, with the reference diameters D_1 , D_2 and D_3 .

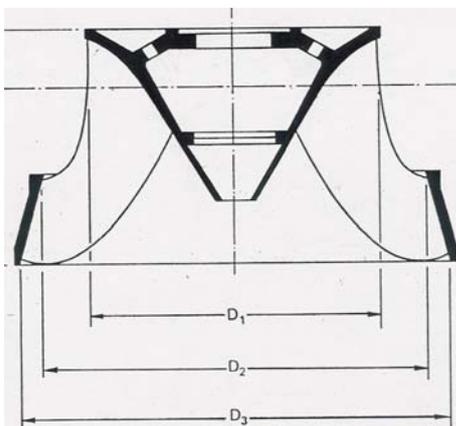


Figure 6.24: Cross section of a Francis Runner

The de Siervo and de Leva¹¹ and Lugaresi et Massa¹³ articles, based on a statistical analysis of more than two hundred existing turbines, enables a preliminary design of the Francis Turbine. As with all statistical analysis, the results will not be sufficient on their own for complete turbine design. They only correspond to standard average solutions, particularly if we consider the cavitation criterion (see chapter 6.1.4.4).

The outlet diameter D_3 is given by equation 6.20.

$$D_3 = 84.5 \cdot (0.31 + 2.488 \cdot n_{QE}) \cdot \frac{\sqrt{H_n}}{60 \cdot n} \quad [\text{m}] \quad (6.20)$$

The inlet diameter D_1 is given by equation 6.21

$$D_1 = (0.4 + \frac{0.095}{n_{QE}}) \cdot D_3 \quad [\text{m}] \quad (6.21)$$

The inlet diameter D_2 is given by equation 6.22 for $n_{QE} > 0.164$

$$D_2 = \frac{D_3}{0.96 + 0.3781 \cdot n_{QE}} \quad [\text{m}] \quad (6.22)$$

For $n_{QE} < 0.164$, we can consider that $D_1 = D_2$

For the other dimension calculations, please refer to the above-mentioned articles.

Kaplan turbines

The Kaplan turbines exhibit much higher specific speeds than Francis and Pelton.

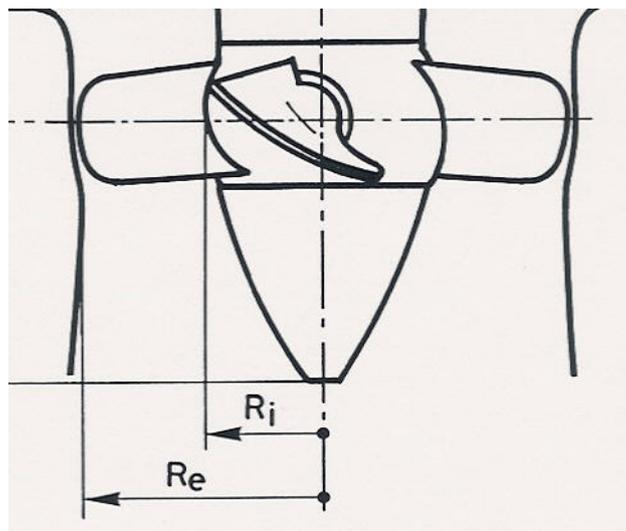


Figure 6.25: Cross section of a Kaplan turbine

In the preliminary project phase the runner outer diameter D_e can be calculated by the equation 6.23.

$$D_e = 84.5 \cdot (0.79 + 1.602 \cdot n_{QE}) \cdot \frac{\sqrt{H_n}}{60 \cdot n} \quad [\text{m}] \quad (6.23)$$

The runner hub diameter D_i can be calculated by the equation 6.24.

$$D_i = (0.25 + \frac{0.0951}{n_{QE}}) \cdot D_e \quad [\text{m}] \quad (6.24)$$

For the other dimensions calculation, please refer to the De Siervo and De Leva¹² or Lugaresi and Massa¹⁴ articles.

6.2.4 Turbine selection criteria

The type, geometry and dimensions of the turbine will be fundamentally conditioned by the following criteria:

- Net head
- Range of discharges through the turbine
- Rotational speed
- Cavitation problems
- Cost

As previously expressed, the preliminary design and choice of a turbine are both iterative processes.

Net head

The gross head is well defined, as the vertical distance between the upstream water surface level at the intake and the downstream water level for reaction turbines or the nozzle axis level for impulse turbines.

As explained in chapter 6.1.1, equation 6.4, the net head is the ratio of the specific hydraulic energy of machine by the acceleration due to gravity. This definition is particularly important, as the remaining kinetic energy in low head schemes cannot be neglected.

The first criterion to take into account in the turbine's selection is the net head. Table 6.3 specifies the range of operating heads for each type of turbine. The table shows some overlapping, as for a certain head several types of turbines can be used.

Table 6.3: Range of heads

Turbine type	Head range in metres
Kaplan and Propeller	$2 < H_n < 40$
Francis	$25 < H_n < 350$
Pelton	$50 < H_n < 1'300$
Crossflow	$5 < H_n < 200$
Turgo	$50 < H_n < 250$

Discharge

A single value of the flow has no significance. It is necessary to know the flow regime, commonly represented by the Flow Duration Curve (FDC) 12 as explained in chapter 3, sections 3.3 and 3.6.

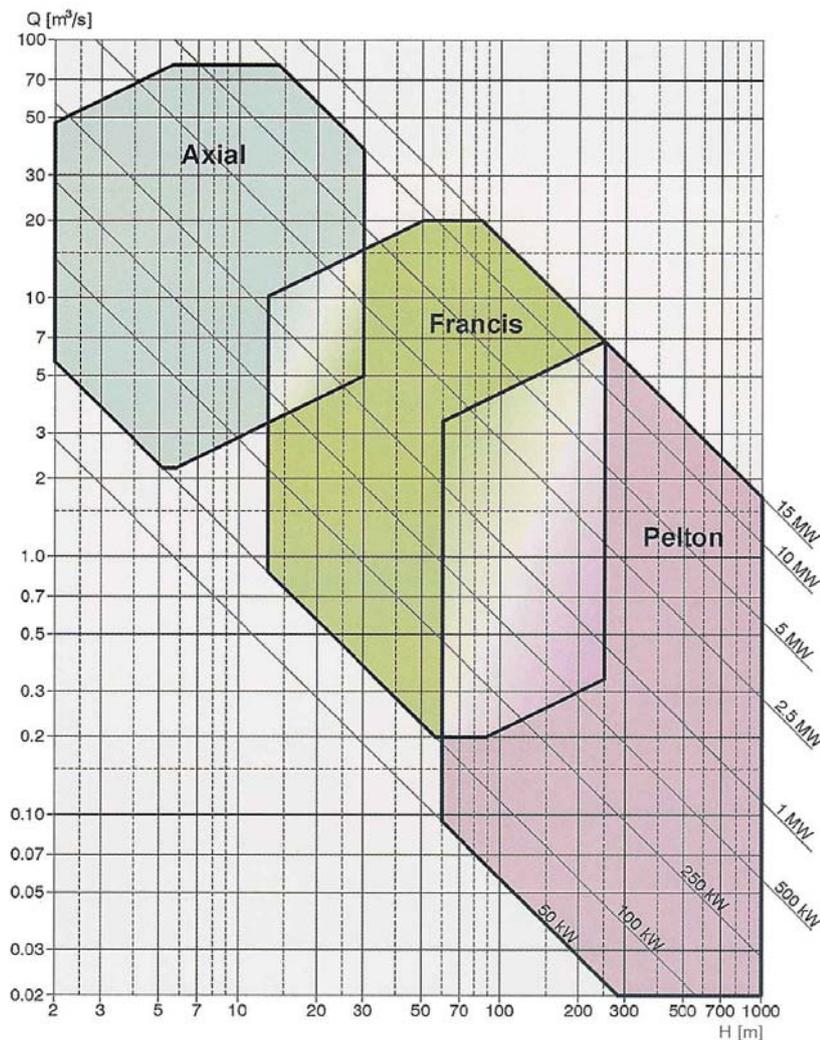


Figure 6.26: Turbines' type field of application.

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 (figure 6.26). 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.

In case of strong flow variation in the range of medium head, a multi-jet Pelton with a low rotational speed will be preferred to a Francis turbine. A similar remark can also be made for Kaplan and Francis in low heads.

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.

Table 6.4: Flow and head variation acceptance

Turbine type	Acceptance of flow variation	Acceptance of head variation
Pelton	High	Low
Francis	Medium	Low
Kaplan double regulated	High	High
Kaplan single regulated	High	Medium
Propeller	Low	Low

Specific speed

The specific speed constitutes a reliable criterion for the selection of the turbine, without any doubt more precise than the conventional enveloping curves, just mentioned.

If we wish to produce electricity in a scheme with 100-m net head and 0.9 m³/s, using a turbine directly coupled to a standard 1500-rpm generator we should begin by computing the specific speed according equation (6.5).

$$n_{QE} = 0.135$$

With this specific speed the only possible selection is a Francis turbine. Otherwise if we accept the possibility of using a lower speed, it could be possible to select, in addition to the Francis, a 4-nozzles Pelton with 600-rpm generator.

If we intend to install a turbine in a 400 m head, 0.42 m³/s scheme, directly coupled to a 1000-rpm generator, we will begin computing the specific speed:

$$n_{QE} = 0.022$$

Which indicates the 1 jet Pelton option, with a diameter $D_1 = 0.815$ m according to equation (6.15).

A two or more jet Pelton would also be possible if required by a highly variable flow requiring a good efficiency at part load.

As previously explained, the Pelton turbines are generally defined by the D_1/B_2 ratio rather than by the specific speed. As a general rule, this ratio has to be higher than 2.7. Such a ratio cannot be obtained without model laboratory developments.

Cavitation

When the hydrodynamic pressure in a liquid flow falls below the vapour pressure of the liquid, there is a formation of the vapour phase. This phenomenon induces the formation of small individual bubbles that are carried out of the low-pressure region by the flow and collapse in regions of higher pressure. The formation of these bubbles and their subsequent collapse gives rise to what is called cavitation. Experience shows that these collapsing bubbles create very high impulse pressures accompanied by substantial noise (in fact a turbine undergoing cavitation sounds as though gravel is passing through it). The repetitive action of such collapse in a reaction turbine close to the runner blades or hub for instance results in pitting of the material. With time this pitting degenerates into cracks formed between the pits, and the metal is snatched from the surface. In a relatively short time the turbine is severely damaged and will need to be shut-off and repaired - if possible.

However cavitation is not a fatality. Laboratory developments allow for a proper hydraulic design to be defined and the operating field of the turbines to be fixed, which can both help in avoiding this problem.

Cavitation is characterised by the cavitation coefficient σ (Thoma's coefficient) defined according to IEC 60193 standard as:

$$\sigma = \frac{NPSE}{gH_n} \quad [-] \quad (6.25)$$

Where NPSE is the net positive suction energy defined as:

$$NPSE = \frac{P_{atm} - P_v}{\rho} + \frac{V^2}{2} - gH_s \quad [-] \quad (6.26)$$

Where:	P_{atm} = atmospheric pressure	[Pa]
	P_v = water vapour pressure	[Pa]
	ρ = water specific density	[kg/m ³]
	g = acceleration due to gravity	[m/s ²]
	V = outlet average velocity	
	H_n = net head	[m]
	H_s = suction head	[m]

To avoid cavitation, the turbine should be installed at least at the H_s as defined by equation (6.27).

$$H_s = \frac{P_{atm} - P_v}{\rho \cdot g} + \frac{V^2}{2 \cdot g} - \sigma \cdot H_n \quad [m] \quad (6.27)$$

A positive value of H_s means that the turbine runner is over the downstream level, a negative value that it is under the downstream level.

As a first approach, one can consider that $V = 2$ m/s.

The Thoma's sigma is usually obtained by a model test, and it is a value furnished by the turbine manufacturer. The above-mentioned statistical studies also relate Thoma's sigma with the specific speed. These specify the equation giving σ as a function of n_{QE} for the Francis and Kaplan turbines:

$$\text{Francis} \quad \sigma = 1.2715 \cdot n_{QE}^{1.41} + \frac{V^2}{2 \cdot g \cdot H_n} \quad [-] \quad (6.28)$$

$$\text{Kaplan} \quad \sigma = 1.5241 \cdot n_{QE}^{1.46} + \frac{V^2}{2 \cdot g \cdot H_n} \quad [-] \quad (6.29)$$

It must be remarked that P_{atm} decreases with the altitude, from roughly 1.01 bar m at the sea level to 0.65 bar at 3000 m above sea level. So then a Francis turbine with a specific speed of 0.150, working under a 100 m head (with a corresponding $\sigma = 0.090$), that is in a plant at sea level, will require a setting of

$$H_s = \frac{101'000 - 880}{1000 \cdot 9.81} + \frac{2^2}{2 \cdot 9.81} - 0.09 \cdot 100 = 1.41 \quad [m]$$

installed in a plant at 2000 m above the sea level will require

$$H_s = \frac{79'440 - 880}{1000 \cdot 9.81} + \frac{2^2}{2 \cdot 9.81} - 0.09 \cdot 100 = -0.79 \quad [m]$$

a setting requiring an excavation.

Figure 6.27 gives an overview of cavitation limits.

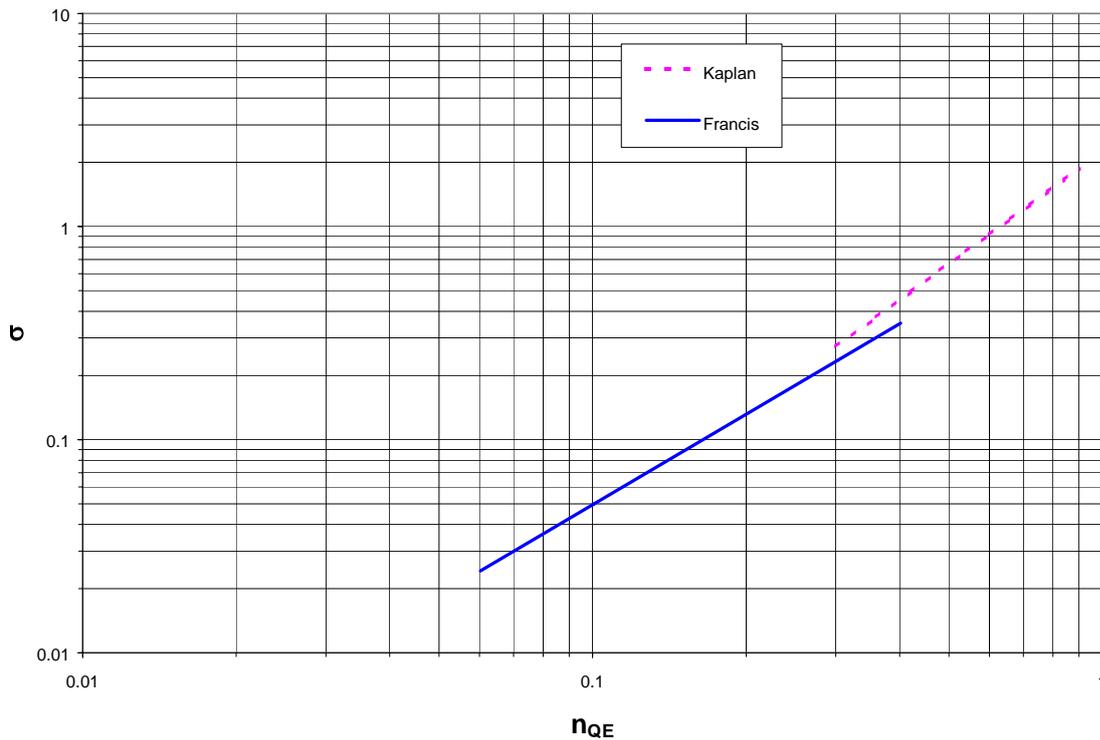


Figure 6.27: Cavitation limits

Equation 6.30 gives a mean to control the concordance between specific speed n_{QE} and cavitation limits.

$$n_{QE} \leq 0.686 \cdot \sigma^{0.5882} \quad [-] \quad (6.30)$$

It has to be noted that local cavitation can occur on Pelton buckets if the inlet edge is not properly designed or if the laboratory tested shape has not been fully respected during manufacture.

Rotational speed

According to equation 6.5 the rotational speed of a turbine is directly linked to its specific speed, flow and net head. In the small hydro schemes standard generators should be installed when possible, so in during turbine selection it must be considered that the generator, either coupled directly or through a speed increaser to the turbine, should reach the synchronous speed, as given in table 6.5.

Table 6.5: Generator synchronisation speed

Number of poles	Frequency		Number of poles	Frequency	
	50 Hz	60Hz		50 Hz	60 Hz
2	3000	3600	16	375	450
4	1500	1800	18	333	400
6	1000	1200	20	300	360
8	750	900	22	272	327
10	600	720	24	250	300
12	500	600	26	231	377
14	428	540	28	214	257

Runaway speed

Each runner profile is characterised by a maximum runaway speed. This is the speed, which the unit can theoretically attain in case of load rejection when the hydraulic power is at its maximum. Depending on the type of turbine, it can attain 2 or 3 times the nominal speed. Table 6.3 shows this ratio for miscellaneous turbines.

It must be remembered that the cost of both generator and eventual speed increaser may be increased when the runaway speed is higher, since they must be designed to withstand it.

Table 6.6: Runaway speeds of turbines

Turbine type	Runaway speed n_{max}/n
Kaplan single regulated	2.0 - 2.6
Kaplan double regulated	2.8 - 3.2
Francis	1.6 – 2.2
Pelton	1.8 – 1.9
Turgo	1.8 – 1.9

6.2.5 Turbine efficiency

It is really important to remember that the efficiency characterises not only the ability of a turbine to exploit a site in an optimal manner but also its hydrodynamic behaviour.

A very average efficiency means that the hydraulic design is not optimum and that some important problems may occur (as for instance cavitation, vibration, etc.) that can strongly reduce the yearly production and damage the turbine.

Each power plant operator should ask the manufacturer for an efficiency guarantee (not output guarantees) based on laboratory developments. It is the only way to get insurance that the turbine will work properly. The origin of the guarantees should be known, even for very small hydro turbines.

Figure 6.28 shows an example of a real site developed without efficiency guarantees and laboratory works.

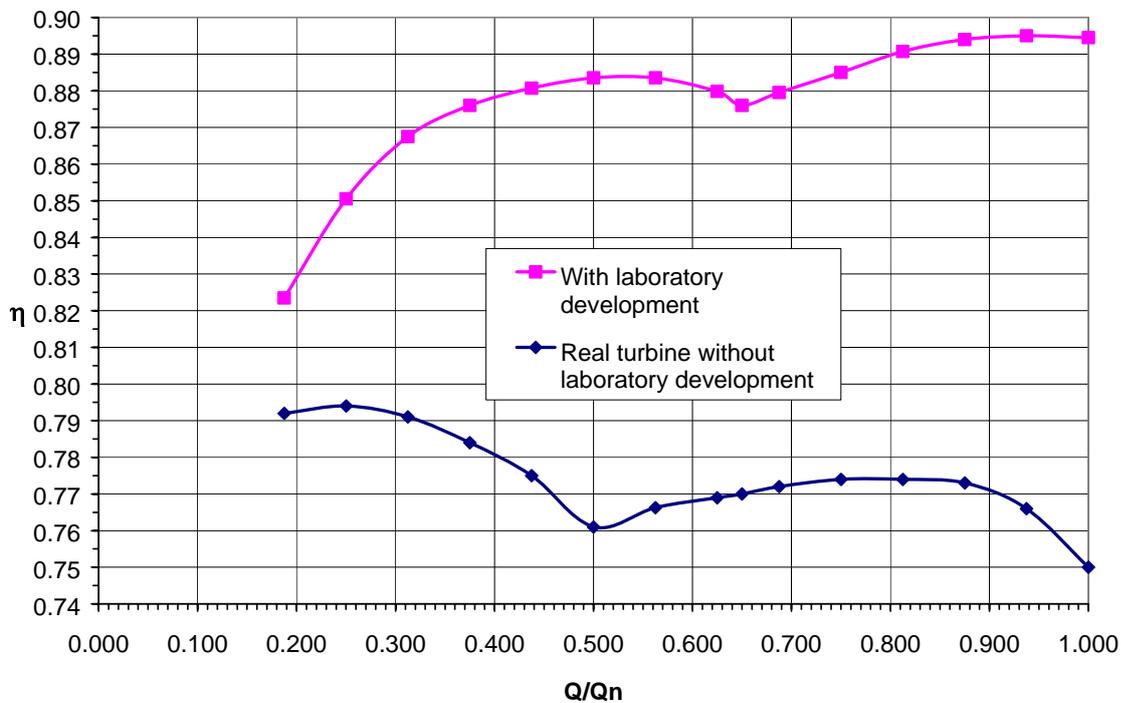


Figure 6.28: Efficiency measurement on a real turbine built without laboratory development.

For the owner who wishes to control the output of a turbine, two methods are available:

The first is to carry out **on site tests** after putting the turbine into service. In order to obtain adequate measurement precision, elaborate techniques, which are difficult to implement and which most often are not suitable for small installations must be used. It is therefore generally necessary to resort to simpler methods, the results of which are always questionable. If the tests demonstrate that guaranteed output is not achieved, it is usually too late to improve the machine. Payment, by the

manufacturer, of contractual penalties never usually compensates for the loss of production sustained by the operator, over the turbine's lifetime.

The second method consists of performing **laboratory tests** on turbines geometrically similar to the industrial prototypes. In the case of small hydropower plants, the size of the models being tested is often quite close to that of the actual machines. The hydraulic behaviour of the turbine may be observed over the whole extent of its operating range. It is thus possible to correct any possible shortcomings **before** the machine is actually built.

The efficiency guaranteed by turbine manufacturers is that which may be verified in accordance with the "International Code for the field acceptance tests of hydraulic turbines" (publication IEC 60041) or, if applied, in accordance with the "International Code for model acceptance tests" (publication IEC 60193). It is defined as the ratio of power supplied by the turbine (mechanical power transmitted by the turbine shaft) to the hydraulic power, as defined in equation 6.1.

$$\eta = \frac{P_{mec}}{P_h} \quad [-] \quad (6.31)$$

As defined in figure 6.29, the turbine is not only limited to the runner. International standards clearly define the limits of the turbine and the manufacturer must give its guarantees according to these limits. The manufacturer also indicates quality criterion that the owner has to respect, such as velocity repartition and flow deviation at the intake in the case of low head schemes.

It should be noted that for impulse turbines (Pelton and Turgo), the head is measured at the point of impact of the jet, which is always above the downstream water level. This effectively amounts to a reduction of the head. The difference is not negligible for medium-head schemes, when comparing the performance of impulse turbines with those of reaction turbines that use the entire available head.

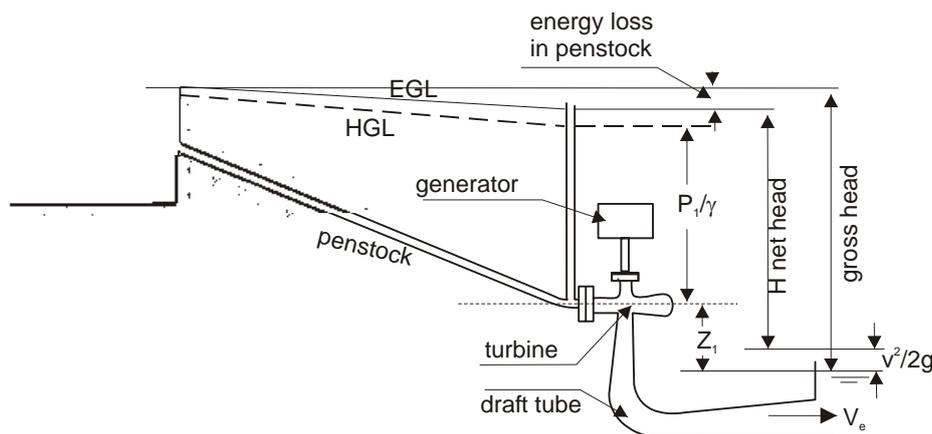


Figure 6.29: Schematic view of the energy losses in an hydro power scheme

Due to the energy losses generated in reaction turbines the runner uses a lower energy than the specific hydraulic energy of the whole machine, as defined in figure 6.30. These losses are essentially friction losses in the spiral case, guide-vanes and runner blades plus kinetic remaining energy in the draft tube.

The draft-tube or diffuser is designed to recover the biggest possible fraction of the kinetic energy of the water leaving the blades. This remaining energy is particularly critical in the very low heads (< 5m), where it may reach up to 80% of the net head (whereas in the medium head it rarely exceeds 3%-4%). The draft-tube has such implications on the turbine operation and efficiency that only the turbine manufacturer can design it properly according to his laboratory developments.

Fig 6.30 (to be used with Table 6.7) indicates the typical efficiency guaranteed by manufacturers for several types of turbine. To estimate the overall efficiency the turbine efficiency must be multiplied by the efficiencies of the speed increaser (if used) and the alternator.

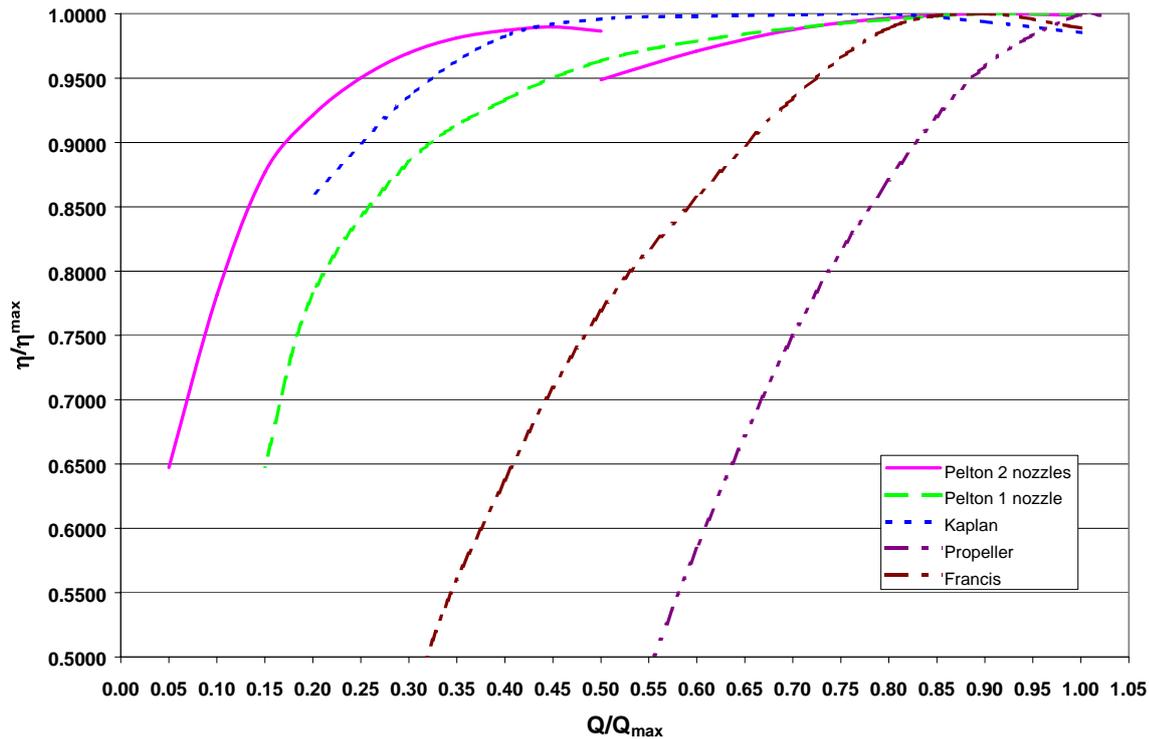


Figure 6.30: Typical small hydro turbines efficiencies

When the flow deviates from that nominal discharge so does the turbine's hydraulic efficiency. As the design discharge of reaction turbines is generally chosen to be different from the best efficiency discharge, the efficiencies given in table 6.7 correspond to best efficiency, but not to efficiency at design or maximum discharge.

Double regulated Kaplan and Pelton turbines can operate satisfactorily over a wide range of flow - upwards from about one fifth of rated discharge. Single regulated Kaplans have acceptable efficiency upward from one-third and Francis turbines from one half of rated discharge. Below 40% of the rated discharge, Francis turbines may show instability resulting in vibration or mechanical shock.

Propeller turbines with fixed guide vanes and blades can operate satisfactorily only over a very limited range close to their rated discharge. It should be noted that single-regulated Kaplan turbines are only efficient if it is the runner that is adjustable.

Table 6.7: Typical efficiencies of small turbines

Turbine type	Best efficiency
Kaplan single regulated	0.91
Kaplan double regulated	0.93
Francis	0.94
Pelton n nozzles	0.90
Pelton 1 nozzle	0.89
Turgo	0.85

6.3 Speed increasers

When the turbine and the generator operate at the same speed and can be placed so that their shafts are in line, direct coupling is the right solution; virtually no power losses are incurred and maintenance is minimal. Turbine manufactures will recommend the type of coupling to be used, either rigid or flexible although a flexible coupling that can tolerate certain misalignment is usually recommended.

In many instances, particularly in low head schemes, turbines run at less than 400 rpm, requiring a speed increaser to meet the 750-1000 rpm of standard alternators. In the range of powers contemplated in small hydro schemes this solution is often more economical than the use of a custom made alternator.

Nowadays alternator manufacturers also propose low speed machines allowing direct coupling.

6.3.1 Speed increaser types

Speed increasers according to the gears used in their construction are classified as:

- Parallel-shaft using helical gears set on parallel axis and are especially attractive for medium power applications. Figure 6.31 shows a vertical configuration, coupled to a vertical Kaplan turbine.
- Bevel gears commonly limited to low power applications using spiral bevel gears for a 90° drive. Figure 6.32 shows a two-phased speed increaser. The first is a parallel gearbox and the second a bevel gear drive.
- Belt speed increaser that is commonly used for small power application and offer maintenance facilities (see figure 6.33).

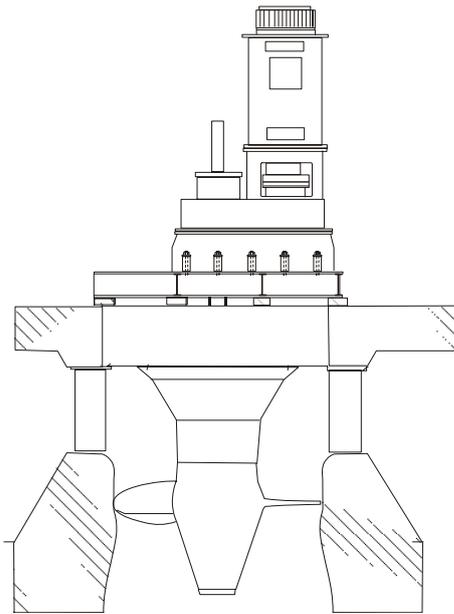


Figure 6.31: Parallel shaft speed increaser

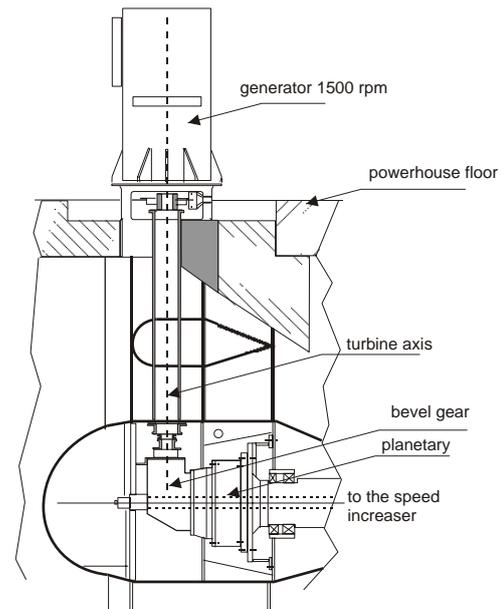


Figure 6.32: Bevel gear speed increaser

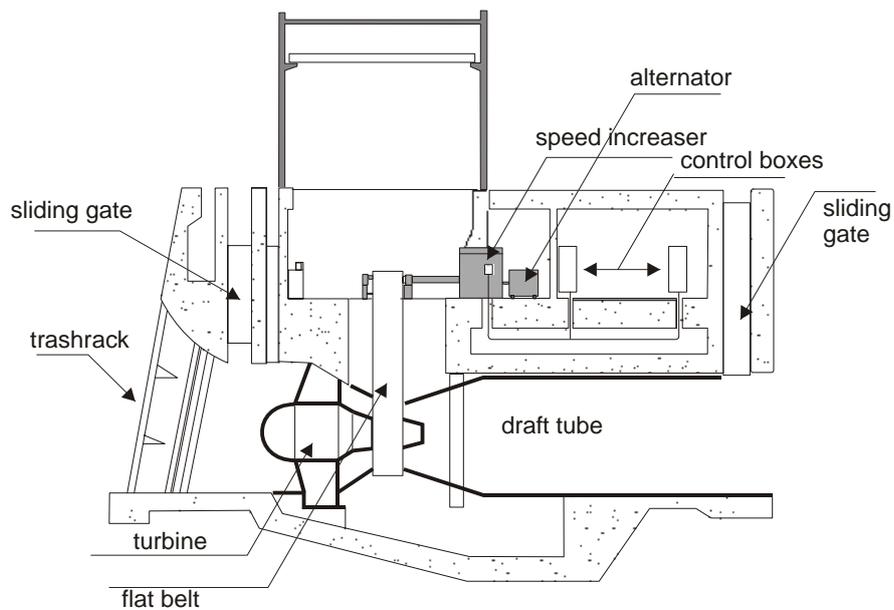


Figure 6.33: Belt speed increaser

6.3.2 Speed increaser design

The gearbox should be designed to ensure, under the most unfavourable conditions, the correct alignment of its components. They are usually fabricated in welded steel with heavy stiffeners to resist the turbine torque and hydraulic axial thrust without apparent deformation.

A lack of synchronism, full load rejection, or any other accident in the system can generate very high critical stresses on the gears. To protect gears against these exceptional strains the speed increaser should incorporate a torque limiter, so that the connector breaks when there is an abnormal force.

To ensure the required level of reliability good lubrication is essential. It is very important that the quality, volume, viscosity and temperature of the oil always stay within specifications. A double lubrication system with two pumps and two oil filters would contribute to the system reliability.

Speed increasers are designed according to international standards (AGMA 2001, B88 or DIN 3990) using very conservative design criteria. These criteria conflict with the need to reduce costs, but no cost savings are possible or recommended without a thorough analysis of the fatigue strains, and a careful shaving of the heat treated gears, a satisfactory stress relieving of the welded boxes, all of which are essential to ensure the durability of a speed increaser. Metallurgical factors including knowledge of the respective advantages and disadvantages of hard casing or nitriding of gears are also essential to optimise the speed increaser.

Selection of journal bearings is also crucial. Under 1 MW the use of roller bearings is usual. Nowadays manufacturers begin to use such technology for turbines up to 5 MW. The other possibility is to use hydrodynamic lubricated bearings that present the following advantages:

- The life of the roller bearings is limited by fatigue whereas the hydrodynamic bearings have a practically unlimited life.
- Hydrodynamic bearings permit a certain oil contamination, whereas roller bearings do not.

6.3.3 Speed increaser maintenance

At least 70% of speed increaser malfunctioning is due to the poor quality or the lack of the lubricant oil. Frequently the oil filters clog or water enters the lubrication circuit. Maintenance should be scheduled either based on predetermined periods of time or –better still by periodic analysis of the lubricant to check that it meets specifications.

Speed increasers substantially increase the noise in the powerhouse and require careful maintenance as their friction losses can exceed 2% of the outlet power, so other alternatives have been investigated, as for instance the use of low speed generators.

6.4 Generators

Generators transform mechanical energy into electrical energy. Although most early hydroelectric systems were of the direct current variety to match early commercial electrical systems, nowadays only three-phase alternating current generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between:

- **Synchronous generators:** They are equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They supply the reactive energy required by the power system when the generator is connected to the grid. Synchronous generators can run isolated from the grid and produce power since excitation is not grid-dependent

- Asynchronous generators:** They are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy. They cannot generate when disconnected from the grid because are incapable of providing their own excitation current. However, they are used in very small stand-alone applications as a cheap solution when the required quality of the electricity supply is not very high.

Below 1 MW, synchronous generators are more expensive than asynchronous generators and are used in power systems where the output of the generator represents a substantial proportion of the power system load. Asynchronous generators are cheaper and are used in stable grids where their output is an insignificant proportion of the power system load. The efficiency should be 95 % for a 100 kW machine and can increase to 97% towards an output power of 1MW. Efficiencies of synchronous generators are slightly higher. In general, when the power exceeds some MVA a synchronous generator is installed.

Recently, variable-speed constant-frequency systems (VSG), in which turbine speed is permitted to fluctuate widely, while the voltage and frequency are kept constant and undistorted, have become available. The frequency converter, which is used to connect the generator via a DC link to the grid can even "synchronise" to the grid before the generator starts rotating. This approach is often proposed as a means of improving performance and reducing cost. However no cost reduction can be achieved using propeller turbines, if runner regulation is replaced only. It is also not possible, to improve the energy production compared to a double-regulated Kaplan turbine. There are nevertheless a number of cases where variable speed operation seems to be a suitable solution, e.g. when the head varies significantly.

The operating voltage of the generator increases with power. The standard generation voltages of 400 V or 690 V allow for the use of standard distributor transformers as outlet transformers and the use of the generated current to feed into the plant power system. Generators of some MVA are usually designed for higher operating voltages up to some kV and connected to the grid using a customised transformer. In this case an independent transformer HT/LT is necessary for the auxiliary power supply of the power plant.

Table 6.8: Typical efficiencies of small generators

Rated power [kW]	Best efficiency
10	0.910
50	0.940
100	0.950
250	0.955
500	0.960
1000	0.970

6.4.1 Generator configurations

Generators can be manufactured with horizontal or vertical axis, independently of the turbine configuration. Figure 6.34 shows a vertical axis Kaplan turbine turning at 214 rpm directly coupled to a custom made 28 poles alternator.

A flywheel is frequently used to smooth-out speed variations and assists the turbine control.

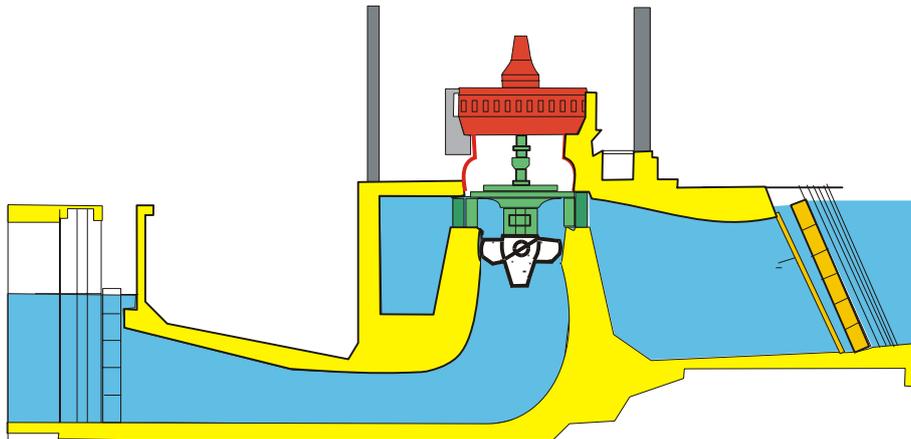


Figure 6.34: Vertical axis generator directly coupled to a Kaplan turbine

Another criterion for characterising generators is how their bearings are positioned. For example it is common practice to install a generator with extra-reinforced bearings supporting the cantilevered runner of a Francis turbine. In that way the turbine axis does not need to cross the draft tube so improving the overall efficiency. The same solution is frequently used with Pelton turbines.

When these generators are small, they have an open cooling system, but for larger units it is recommended that a closed cooling circuit provided with air-water heat exchangers.

6.4.2 Exciters

The exciting current for the synchronous generator can be supplied by a small DC generator, known as the exciter, driven from the main shaft. The power absorbed by this DC generator amounts to 0.5% - 1.0% of the total generator power. Nowadays a static exciter usually replaces the DC generator, but there are still many rotating exciters in operation.

Rotating exciters.

The field coils of both the main generator and the exciter generator are usually mounted on the main shaft. In larger generators a pilot exciter with permanent magnet excitation is also used. It supplies the exciting current to the main exciter, which in turn supplies the exciting current for the rotor of the generator.

Brushless exciters

A small generator has its field coils on the stator and generates AC current in the rotor windings. A solid state rectifier rotates with the shaft, converting the AC output from the small generator into the DC, which is supplied to the rotating field coils of the main generator without the need for brushes. The voltage regulation is achieved by controlling the current in the field coils of the small generator.

Static exciters

A static exciter is a grid connected rectifier that provides DC current to the generator field coils instead of the rotating exciter. The voltage and power factor control works in the same way as with the rotating device. Static exciters are robust, easy to maintain and have a high efficiency. The response to the generator voltage oscillations is very good.

6.4.3 Voltage regulation and synchronisation

Asynchronous generators

An asynchronous generator needs to absorb reactive power from the three-phase mains supply to ensure its magnetisation is even. The mains supply defines the frequency of the stator rotating flux and hence the synchronous speed above which the rotor shaft must be driven.

On start-up, the turbine is accelerated to a speed slightly above the synchronous speed of the generator, when a velocity relay closes the main line switch. From this hyper-synchronised state the generator speed will be reduced to synchronous speed by feeding current into the grid. Speed deviations from synchronous speed will generate a driving or resisting torque that balances in the area of stable operation.

Synchronous generators

The synchronous generator is started before connecting it to the mains by the turbine rotation. By gradually accelerating the turbine, the generator must be synchronised with the mains, regulating the voltage, frequency, phase angle and rotating sense. When all these values are controlled correctly, the generator can be switched to the grid. In the case of an isolated or off grid operation, the voltage controller maintains a predefined constant voltage, independent of the load. In case of the mains supply, the controller maintains the predefined power factor or reactive power.

6.5 Turbine control

Turbines are designed for a certain net head and discharge. Any deviation from these parameters must be compensated for by opening or closing the control devices, such as the wicket-gates, vanes, spear nozzles or valves, to keep either the outlet power, the level of the water surface in the intake, or the turbine discharge constant.

In schemes connected to an isolated network, the parameter that needs to be controlled is the turbine speed, which controls the frequency. In an off grid system, if the generator becomes overloaded the turbine slows-down therefore an increase of the flow of water is needed to ensure the turbine does not stall. If there is not enough water to do this then either some of the load must be removed or the turbine will have to be shut down. Conversely if the load decreases then the flow to the turbine is

decreased or it can be kept constant and the extra energy can be dumped into an electric ballast load connected to the generator terminals.

In the first approach, speed (frequency) regulation is normally accomplished through flow control; once a gate opening is calculated, the actuator gives the necessary instruction to the servomotor, which results in an extension or retraction of the servo's rod. To ensure that the rod actually reaches the calculated position, feedback is provided to the electronic actuator. These devices are called "speed governors".

In the second approach it is assumed that, at full load, constant head and flow, the turbine will operate at design speed, so maintaining full load from the generator; this will run at a constant speed. If the load decreases the turbine will tend to increase its speed. An electronic sensor, measuring the frequency, detects the deviation and a reliable and inexpensive electronic load governor, switches on pre-set resistance and so maintains the system frequency accurately.

The controllers that follow the first approach do not have any power limit. The Electronic Load Governors, working according to the second approach rarely exceed 100 kW capacity.

Speed Governors

A governor is a combination of devices and mechanisms, which detect speed deviation and convert it into a change in servomotor position. A speed-sensing element detects the deviation from the set point; this deviation signal is converted and amplified to excite an actuator, hydraulic or electric, that controls the water flow to the turbine. In a Francis turbine, where there is a reduction in water flow you need to rotate the wicket-gates. For this, a powerful governor is required to overcome the hydraulic and frictional forces and to maintain the wicket-gates in a partially closed position or to close them completely.

Several types of governors are available varying from old fashioned purely mechanical to mechanical-hydraulic to electrical-hydraulic and mechanical-electrical. The purely mechanical governor is used with fairly small turbines, because its control valve is easy to operate and does not require a big effort. These governors use a flyball mass mechanism driven by the turbine shaft. The output from this device - the flyball axis descends or ascends according to the turbine speed - directly drives the valve located at the entrance to the turbine.

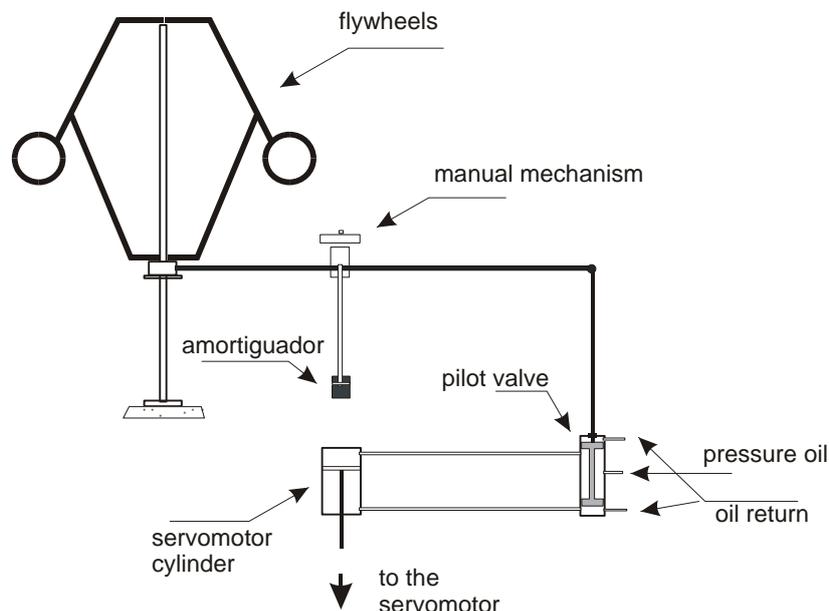


Figure 6.35: mechanical speed governor

In the past, the most commonly used type was the oil-pressure governor (Fig 6.35) that also uses a flyball mechanism, which is lighter and more precise than that used in a purely mechanical governor. When the turbine is overloaded, the flyballs slowdown, the balls drop, and the sleeve of the pilot valve rises to open access to the upper chamber of the servomotor. The oil under pressure enters the upper chamber of the servomotor to rotate the wicket-gates mechanism, increase the flow, and consequently the rotational speed and the frequency.

In a modern electrical-hydraulic governor a sensor located on the generator shaft continuously senses the turbine speed. The input is fed into a summing junction, where it is compared to a speed reference. If the speed sensor signal differs from the reference signal, it emits an error signal (positive or negative) that, once amplified, is sent to the servomotor so this can act in the required sense. In general the actuator is powered by a hydraulic power unit (photo 6.10) consisting of a sump for oil storage, an electric motor operated pump to supply high pressure oil to the system, an accumulator where the oil under pressure is stored, oil control valves and a hydraulic cylinder. All these regulation systems, as have been described, operate by continuously adjusting the wicket-gates position back and forth. To provide quick and stable adjustment of the wicket-gates, and/or of the runner blades, with the least amount of over or under speed deviations during system changes a further device is needed. In oil pressure governors, as may be seen in figure 6.37, this is achieved by interposing a "dash pot" that delays the opening of the pilot valve. In electrical-hydraulic governors the degree of sophistication is much greater, so that the adjustment can be proportional, integral and derivative (PID) giving a minimum variation in the controlling process.

An asynchronous generator connected to a stable electric grid, does not need any controller, because its frequency is controlled by the mains. Notwithstanding this, when the generator is disconnected from the mains the turbine accelerates up to runaway speed of the turbine. Generator and speed increaser have to be designed to withstand this speed long enough until the water flow is closed by the controlling system (guide vanes or valve).

To ensure the control of the turbine speed by regulating the water flow, certain inertia of the rotating components is required. Additional inertia can be provided by a flywheel, on the turbine, or the generator shaft. When the main switch disconnects the generator, the power excess accelerates the flywheel; later, when the switch reconnects the load, the deceleration of this inertia flywheel supplies additional power that helps to minimise speed variation. The basic equation of the rotating system is the following:

$$J \cdot \frac{d\Omega}{dt} = T_t - T_L \quad \text{[Nm]} \quad (6.32)$$

- where: J = moment of inertia of the rotating components [kg m²]
- Ω = angular velocity [rad/s]
- T_t = torque of turbine [Nm]
- T_L = torque due to load [Nm]

When T_t is equal to T_L , $d \Omega / dt = 0$ and $\Omega = \text{constant}$, so the operation is steady. When T_t is greater or smaller than T_L , Ω is not constant and the governor must intervene so that the turbine output

matches the generator load. But it should not be forgotten that the control of the water flow introduces a new factor: the speed variations on the water column formed by the waterways.

The flywheel effect of the rotating components is stabilising whereas the water column effect is destabilising. The start-up time of the rotating system, the time required to accelerate the unit from zero rotational speed to operating speed is given by

$$t_m = J \frac{\Omega^2}{P} = \frac{\Omega \cdot R^2 \cdot n^2}{5086 \cdot P} \quad [s] \quad (6.33)$$

where the rotating inertia of the unit is given by the weight of all rotating parts multiplied by the square of the radius of gyration: ΩR^2 , P is the rated power in kW and n the turbine speed (rpm)

The water starting time, needed to accelerate the water column from zero velocity to some other velocity V, at a constant specific hydraulic energy gH is given by:

$$t_v = \frac{\sum L \cdot V}{gH} \quad [s] \quad (6.34)$$

where	gH = specific hydraulic energy of the turbine	[J/kg]
	L = length of water column	[m]
	V = velocity of the water	[m/s]

To achieve good regulation, it is necessary that $T_m/T_w > 4$. Realistic water starting times do not exceed 2.5 sec. If it is larger, modification of the water conduits must be considered - either by decreasing the velocity or the length of the conduits by installing a surge tank. The possibility of adding a flywheel to the generator to increase the inertia rotating parts can also be considered. It should be noted that an increase in the inertia of the rotating parts would improve the waterhammer effect and decrease the runaway speed.

6.6 Switchgear equipment

In many countries the electricity supply regulations place a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent producer must operate his plant in such a way that the utility is able to fulfil its obligations. Therefore various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer. The generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both power transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

The asynchronous generator protection must include, among other devices: a reverse-power relay giving protection against motoring; differential current relays against internal faults in the generator stator winding; a ground-fault relay providing system backup as well as generator ground-fault protection, etc. The power transformer protection includes an instantaneous over-current relay and a timed over-current relay to protect the main transformer when a fault is detected in the bus system or an internal fault in the main power transformer occurs.

The independent producer is responsible for earthing arrangements within his installation. This must be designed in agreement with the public utility. The earthing arrangement will be dependent on the number of units in use and the independent producer's own system configuration and method of operation.

Metering equipment must be installed at the point of supply to record measurements according to the requirements of the electric utility.

Figure 6.38 shows a single-line diagram corresponding to a power plant with a single unit. In the high voltage side there is a line circuit breaker and a line disconnection switch - combined with a grounding switch - to disconnect the power generating unit and main transformer from the transmission line. Metering is achieved through the corresponding P.T and C.T. A generator circuit breaker is included as an extra protection for the generator unit. A transformer provides energy for the operation of intake gates, shutoff valves, servomotors, oil compressors etc. in the station service.

Greater complexity may be expected in multiunit stations where flexibility and continuity of service are important.

6.7 Automatic control

Small hydro schemes are normally unattended and operated through an automatic control system. Because not all power plants are alike, it is almost impossible to determine the extent of automation that should be included in a given system, but some requirements are of general application:

- a) The system must include the necessary relays and devices to detect malfunctioning of a serious nature and then act to bring the unit or the entire plant to a safe de-energised condition.
- b) Relevant operational data of the plant should be collected and made readily available for making operating decisions, and stored in a database for later evaluation of plant performance.
- c) An intelligent control system should be included to allow for full plant operation in an unattended environment.
- d) It must be possible to access the control system from a remote location and override any automatic decisions.
- e) The system should be able to communicate with similar units, up and downstream, for the purpose of optimising operating procedures.
- f) Fault anticipation constitutes an enhancement to the control system. Using an expert system, fed with baseline operational data, it is possible to anticipate faults before they occur and take corrective action so that the fault does not occur.

The system must be configured by modules. An analogue-to-digital conversion module for measurement of water level, wicket-gate position, blade angles, instantaneous power output, temperatures, etc. A digital-to-analogue converter module to drive hydraulic valves, chart recorders, etc. A counter module to count generated kWh pulses, rain gauge pulses, flow pulses, etc. and a "smart" telemetry module providing the interface for offsite communications, via dial-up telephone lines, radio link or other communication technologies. This modular system approach is well suited to the widely varying requirements encountered in hydropower control, and permits both hardware and software to be standardised. Cost reduction can be realised through the use of a standard system and modular software allows for easy maintenance.

Automatic control systems can significantly reduce the cost of energy production by reducing maintenance and increasing reliability, while running the turbines more efficiently and producing more energy from the available water.

With the tremendous development of desktop computers, their prices are now very low. Many manufacturers supply standardised data acquisition systems. New and cheap peripheral equipment, easily connected to a portable computers, are the "watch-dogs"- helping to monitor and replace control equipment in the event of failure is available and easy to integrate at low price. Improved graphic programming techniques assist the development of easy to use software with graphic user interfaces. Due to the rapid development of digital technologies, the differences between hardware platforms such as PLCs, micro-controllers and industry PCs, disappear for the operator.

6.8 Ancillary electrical equipment

6.8.1 Plant service transformer

Electrical consumption including lighting and station mechanical auxiliaries may require from 1 to 3 percent of the plant capacity; the higher percentage applies to micro hydro (less than 500 kW). The service transformer must be designed to take these intermittent loads into account. If possible, two alternative supplies, with automatic changeover, should be used to ensure service in an unattended plant.

6.8.2 DC control power supply

It is generally recommended that remotely controlled plants are equipped with an emergency 24 V DC back-up power supply from a battery in order to allow plant control for shutdown after a grid failure and communication with the system at any time. The ampere-hour capacity must be such that, on loss of charging current, full control is ensured for as long as it may be required to take corrective action.

6.8.3 Headwater and tailwater recorders

In a hydro plant, provisions should be made to record both the headwater and tailwater. The simplest way is to fix, securely in the stream, a board marked with meters and centimetres in the style of a levelling staff, however someone must physically observe and record the measurements. In powerhouses provided with automatic control the best solution is to use transducers connected to the computer via the data acquisition equipment.

Nowadays measuring units - a sensor - records the measurement variable and converts it into a signal that is transmitted to the processing unit. The measurement sensor must always be installed at the measurement site, where the level has to be measured. - Usually subject to rough environmental

conditions and of difficult access - whereas the processing unit is usually separated and placed in a well protected environment easily accessible for operation and service.

There is a wide range of sensors each one using a variety of measuring principles. It must be realised that the point of the level measurement needs to be selected carefully in order to represent the whole forebay. According to the Bernoulli principle, a change in the current speed causes a change in the dynamic pressure and consequently in the apparent water level as measured by the pressure sensor. If the measurement site is located in the inflow or outflow structures, where high current velocities can occur, the measurement will give false results. The level sensor can transmit the signal by using the hydrostatic method (figure 6.36 a) or the pneumatic (bubble) method (figure 6.36 b). In the first method care should be taken so that all the tubes for pressure transmission are dimensioned and laid in such a way that they cannot be obstructed nor air allowed accumulating within them. In the second, the sensor orifice is located lower than the corresponding level at the start of the measurement, and no water can penetrate and collect in the lines. In the solution shown in figure 6.36 a), floating material can damage the instrument. The best solution is the concealed assembly of all parts together within the wall as shown in figure 6.36 b) and c).

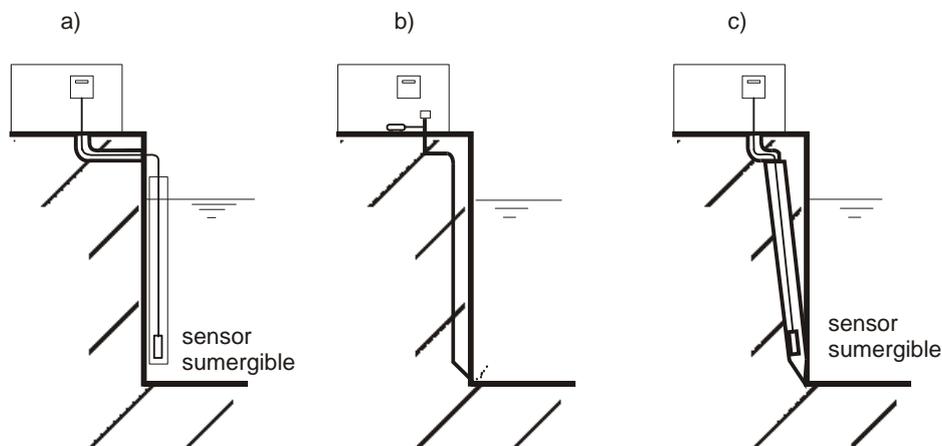


Figure 6.36 Level measurement

6.8.4 Outdoor substation

The so-called water-to-wire system usually includes the substation. A line breaker must separate the plant including the step-up transformer from the grid in case of faults in the power plant. PTs and CTs for kWh and kW metering are normally mounted at the substation, at the connecting link between the plant-out conductors and the take-off line to the grid. In areas with very high environmental sensitivity the substation is enclosed in the powerhouse, and the transmission cables, leave it along the penstock. Lightning arresters for protection against line surges or lightning strikes in the nearby grid are usually mounted in the substation structure.

6.9 Examples

The following example will help in understanding the concepts exposed in this chapter and particularly the use of the specific speed tool.

Selecting a turbine to equip a 200-m net head scheme with a nominal flow of 1.5 m³/sec. The powerhouse is located at an altitude of 1000 m over the sea level.

According to table 6.3 or to figure 6.26 the plot of head and flow falls into the envelopes of a Francis and a Pelton turbine. The turbine speed is given as a function of n_{QE} by equation 6.5:

$$n = \frac{n_{QE} \cdot E^{\frac{3}{4}}}{\sqrt{Q}} = \frac{n_{QE} \cdot (9.81 \cdot 200)^{\frac{3}{4}}}{\sqrt{1.5}} = 240.7 \cdot n_{QE} \quad [\text{t/s}]$$

If we select a **one nozzle Pelton**, the maximum value for n_{QE} according to table 6.2, will be 0.025. The corresponding rotational speed would be 6 t/s = 360 t/min.

As we intend to use direct coupling, the rotational speed has to be synchronous, according to table 6.5. In this case, we would be obliged to choose a 333 t/min rotational speed (5.55 t/s = 34.87 rad/s).

According to 6.5, the corresponding n_{QE} would be:

$$n_{QE} = \frac{n \cdot \sqrt{Q}}{E^{\frac{3}{4}}} = \frac{5.55 \cdot \sqrt{1.5}}{(9.81 \cdot 200)^{\frac{3}{4}}} = 0.023 \quad [-]$$

The main Pelton dimensions according to 6.16, 6.17 and 6.18 would be:

$$D_1 = 0.68 \cdot \frac{\sqrt{H_n}}{n} = 0.68 \cdot \frac{\sqrt{200}}{5.55} = 1.733 \quad [\text{m}]$$

$$B_2 = 1.68 \cdot \frac{Q}{n_{jet} \cdot \sqrt{H_n}} = 1.68 \cdot \frac{1.5}{1 \cdot \sqrt{200}} = 0.547 \quad [\text{m}]$$

$$D_e = 1.178 \cdot \frac{Q}{n_{jet} \cdot \sqrt{gH}} = 1.178 \cdot \frac{1.5}{1 \cdot \sqrt{9.81 \cdot 200}} = 0.217 \quad [\text{m}]$$

Quite huge dimensions are not very realistic from an economical point of view.

If we now consider a **4-nozzle Pelton**, the maximum specific speed (according to table 6.2) would be

$$n_{QE} \leq 0.025 \cdot n^{0.5} = 0.025 \cdot 4^{0.5} = 0.050$$

Using the same calculation as for the one nozzle option, the rotational speed would be 600 rpm and the corresponding n_{QE} would be 0.042.

The main Pelton dimensions would be $D_1 = 0.962$ m, $B_2 = 0.274$ m and $D_e = 0.108$ m which are quite reasonable.

If we now select a **Francis turbine**, the maximum value of n_{QE} would be 0.33 (table 6.2). Using equation 6.5, the corresponding speed would be $n = 76.43$ t/s or 4'765.8 rpm, which is far from a realistic synchronous rotational speed. For this reason, we will choose the maximum usual value, which is 1,500 rpm.

According to 6.5, the corresponding n_{QE} would be:

$$n_{QE} = \frac{n \cdot \sqrt{Q}}{E^{3/4}} = \frac{25 \cdot \sqrt{1.5}}{(9.81 \cdot 200)^{3/4}} = 0.104 \quad [-]$$

The main Francis runner dimensions according to 6.20, 6.21 and 6.22 would be:

$$D_3 = 84.5 \cdot (0.31 + 2.488 \cdot n_{QE}) \cdot \frac{\sqrt{H_n}}{60 \cdot n} = 84.5 \cdot (0.31 + 2.488 \cdot 0.104) \cdot \frac{\sqrt{200}}{60 \cdot 25} = 0.453 \quad [m]$$

$$D_1 = (0.4 + \frac{0.0950}{n_{QE}}) \cdot D_3 = (0.4 + \frac{0.0950}{0.104}) \cdot 0.453 = 0.595 \quad [m]$$

As $n_{QE} < 0.164$, we can consider than $D_2 = D_1 = 0.595$ m.

According to equation 6.28, the cavitation coefficient would be:

$$\sigma = 1.2715 \cdot n_{QE}^{1.41} + \frac{V^2}{2 \cdot g \cdot H_n} = 1.2715 \cdot 0.104^{1.41} + \frac{2^2}{2 \cdot 9.81 \cdot 200} = 0.0533 \quad [-]$$

According to equation 6.27, the setting would be:

$$H_s = \frac{P_{atm} - P_v}{\rho \cdot g} + \frac{V^2}{2 \cdot g} - \sigma \cdot H_n = \frac{90'250 - 880}{1'000 \cdot 9.81} + \frac{2^2}{2 \cdot 9.81} - 0.0533 \cdot 200 = -1.35 \quad [m]$$

A setting that requires important excavation.

If we have selected a Francis running at 1000 rpm we would have had:

$n_{QE} = 0.069$, $D_3 = 0.576$ m, $D_1 = 1.02$ m, $\sigma = 0.0305$ and $H_s = 3.21$ m which does not need excavation.

The final choice will be economical. If the flow strongly varies, a 4-nozzle Pelton could be a good choice. If it is not the case, a 1000-rpm Francis that does not need any excavation could be the best alternative.

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CHAPTER 7: ENVIRONMENTAL IMPACT AND ITS MITIGATION

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7 ENVIRONMENTAL IMPACT AND ITS MITIGATION¹

7.1 Introduction

The “Third Conference of the Parties to the United Nations Framework Convention on Climate Change” was held in Kyoto in December 1997. This was the second initiative after the historic Rio Conference on Environment and Development in June 1992. Even earlier, the European Union had already recognised the urgent need to tackle the climate change issue. The “White Paper for a Community Strategy and Action Plan entitled: “Energy for the future: renewable sources of energy” was subsequently drafted providing a significant step forward.

Finally, the “Directive/77/EC of the European Parliament and of the council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market” set clear community targets. The global indicative target of 12% RE of gross domestic energy consumption by 2010 was stated. To achieve this ambitious goal all Member States have been required to set national indicative targets for the consumption of electricity produced from renewable sources.

A strategic study for the development of Small Hydro Power in the European Union: “Blue Age for a Green Europe” was completed in 2002 and gives a highly interesting survey of the potential of SHP by different approaches. EU countries estimate, under economic and environmental constraints, an increase in capacity of 1111 MW by upgrading existing plants (annual production of 4518 GWh) and an increase in capacity of 4828 MW by the realisation of new small hydroelectric plants (annual production of 19645 GWh).

The technical potential with only technical constraints would represent a doubling of above mentioned figures: 2080 MW (8100 GWh/year) by upgrading existing plants and 9615 (38058 GWh/y) by new plants could be achieved theoretically. The achievement of the “theoretical” objective (46158 GWh/y) will imply an annual reduction of 20 million tonnes of CO₂ emissions based on a prudential value (gas fired plants) of 0.43 kg_{CO2}/kWh.

However, under present trends the above objective will not be attained so long as the administrative procedures to authorise the use of water are not accelerated. Hundreds, if not thousands, of authorisation requests are pending approval, the delay being caused mainly by perceived conflict with the environment. Some environmental agencies seem to justify or at least excuse - this blockade on the grounds of the low capacity of the small plants. It seems to be forgotten that by definition, renewable energies are decentralised and that currently only small hydro power plants and the wind turbines can significantly contribute to renewable electricity production.

At the same time whilst it should be accepted that electricity production in small hydro plants does not produce carbon dioxide or liquid pollutants, the fact is that due to their location in sensitive areas local impacts are not always negligible. The significant global advantages of small hydropower must not prevent the identification of burdens and impacts at local level and the taking of necessary mitigation actions. Large thermal plants, because of their economic relevance and scale, are authorised at very high administrative levels and in some cases, their impacts cannot be mitigated at present. A small hydropower scheme producing impacts that usually can be mitigated is considered at lower administrative levels, where the influence of pressure groups - angling associations, ecologists, etc.- is greater.

It is not difficult to identify the impacts, but to decide which mitigation measures should be undertaken it is not simple, because these are usually dictated by subjective arguments. It is therefore strongly recommended to establish a permanent dialogue with the environmental authorities as a very first step in the design phase. Even if this negotiation must be considered on a project-by-project basis it would be convenient to provide a few guidelines that will help the designer to propose mitigating measures that can easily be agreed with the licensing authorities.

Recently, the implementation of the Water Framework Directive will introduce severe additional demands in ecological terms. There is little doubt, that the fulfilling of ecological aims such as the construction of fish bypass systems or the reduction of water through increased reserved flow has significant cost implications and reduces the viability of SHP. The achievement of environmental goals is not dependent on the ideological resistance of the developer of the site but on his economical restrictions. In reality, the “environmental problem” has economical parents.

7.2 Burdens and impacts identification

Impacts of hydropower schemes are highly location and technology specific. A high mountain diversion scheme situated in a highly sensitive area is more likely to generate an impact than an integral low-head scheme in a valley. The upgrading and extension of existing facilities, which will be given priority in Europe, generates impacts that are quite different from an entirely new scheme. For example, in mountain diversion projects that use the large change in elevation of a river, the water is diverted from the main river and re-enters again at the tailwater below the power plant. In this case, entire areas of the main river may be bypassed by a large volume of water, when the plant is in operation.

Given in Table 7.1 and 7.2 below is an exhaustive description of possible impacts, based on European studies² dealing with externalities, and made by groups of experts that perform Environmental Impact Assessments. However is not certain that all or most of this list of descriptions will be applicable to a specific project. In the list are identified the event, persons or things affected, impact and priority at local and national levels.

Table 7.1: Impacts during Construction

Events during construction	Persons or things affected	Impact	Priority
Geological Surveys	Wildlife	Noise	Low
Existing Vegetation Cutting	Forestry	Alteration of habitat	Medium
Enlargement of Existing Roads	General public	Creation of opportunities, alteration of habitat	Medium
Earth Moving	Site geology	Slope stability	Low
Tunnels Excavation	Site hydro-geology	Alteration of groundwater circulation	Low
Permanent Filling Material on Slopes	Site geology	Slope stability	Low
Embankment Realisation	Aquatic life, site hydro-morphology	Alteration of river hydraulic	Medium
Creation of Temporary Earth Accumulations	Site geology	Slope stability	Low
Temporary Displacement of Persons, Roads, Electric Lines	General public		Negligible
Realisation of Roads and Sheds for the Yard	Wildlife, general public	Visual intrusion, wildlife disturbance	Low
Water Courses Dredging	Aquatic ecosystem	Alteration of habitat	Medium
Temporary Diversion of Rivers	Aquatic ecosystem	Alteration of habitat	High
Use of Excavators, Trucks, Helicopters, Cars for the Personnel, Blondins	Wildlife, general public	Noise	High
Human Presence During the Works on Site	Wildlife, general public	Noise	Low

Table 7.2: Impacts during Operation

Events during operation	Persons or things affected	Impact	Priority
Renewable Energy Production	General public	Reduction of Pollutants	High
Watercourses Damming	Aquatic ecosystem	Modification of habitat	High
Permanent Works in the Riverbed	Aquatic ecosystem	Modification of habitat	High
Diversion of Watercourses	Aquatic ecosystem	Modification of habitat	High
Penstocks	Wildlife	Visual intrusion	Medium
New Electric Lines	General public, wildlife	Visual intrusion	Low
Riprap	Aquatic ecosystem, general public	Modification of habitat, visual intrusion	Low
Levees	Aquatic ecosystem, general public	Modification of habitat, visual intrusion	Low
Flow Rate modification	Fish	Modification of habitat	High
	Plants	Modification of habitat	Medium
	General public	Modification of recreational activities	
Noise from electromechanical equipment	General public	Alteration of life quality	Low
Removal of material from streambed	Aquatic life, General public	Improvement of water quality	high

7.3 Impacts in the construction phase

Schemes of the diversion type, multipurpose reservoir, inserted on an irrigation canal or built into a water supply system produce very different impacts from one another, from both a quantitative and qualitative viewpoint. A scheme making use of a multipurpose dam has practically no unfavourable impacts, since it is understood that when the dam was built the necessary mitigating measures were already incorporated. Even the location of the powerhouse will be at the base and shall not alter the ecological system.

Schemes integrated in an irrigation canal or in a water supply pipe system will not introduce new impacts over those generated when the canal and the pipe system were developed. On the other hand, diversion schemes present very particular aspects that need to be analysed.

7.3.1 Reservoirs

The impacts generated by the construction of a dam and the creation of the adjoining reservoir include, in addition to the loss of ground, the construction and opening of construction roads, working platforms, excavation works, blasting and even -depending of the dam size- concrete manufacturing plants. Other non-negligible impacts are the barrier effect and the alteration of flow consequent to a river regulation that did not exist before. It has to be underlined that reservoirs are in fact not typical for small hydropower plants. The majority of SHP belongs to the run-off type without any big, dam-like construction works.

However, the impacts generated by the construction of a dam do not differ from those induced by any large-scale infrastructure development, whose effects and mitigating measures are well known.

7.3.2 Water intakes, open canals, penstocks, tailraces

The impacts generated by the construction of these structures are well known and have been described in Table 1, e.g. noise affecting the life of animals, danger of erosion due to the loss of

vegetation through excavation work, turbidity of the water and downstream sediment deposition, etc. To mitigate such impacts it is strongly recommended that the excavation work should be undertaken in the low water season and the disturbed ground restored as soon as possible. In any case these impacts are always transitory and do not constitute a serious obstacle to the administrative authorisation procedure.

In view of its protective role against riverine erosion it is wise to restore and reinforce the riverbank vegetation that may have been damaged during construction of the hydraulic structures. It should be noted that the ground should be repopulated with indigenous species, best adapted to the local conditions.

The impact assessment study should take account of the effects of dispersing excavated material in the stream and the unfavourable consequences of construction workers living in a usually uninhabited area during the construction period. This impact, which may be negative if the scheme is located in a natural park, would be positive in a non-sensitive area by increasing the level of its activity. Vehicle emissions, excavation dust, the high noise level and other minor burdens contribute to damaging the environment when the scheme is located in sensitive areas. To mitigate the above impacts the traffic operation must be carefully planned to eliminate unnecessary movements and to keep all traffic to a minimum.

On the positive side, it should be noted that the increase in the level of activity in an area, by using local manpower and small local subcontractors during the construction phase is to be welcomed.

7.4 Impacts arising from the operation of the scheme

7.4.1 Sonic impacts

The allowable level of noise depends on the local population or isolated houses near to the powerhouse. The noise comes mainly from the turbines and, when used, from the speed increasers. Nowadays noise inside the powerhouse can be reduced, if necessary, to levels in the order of 70 dBA, almost imperceptible when outside.

Concerning sonic impact, the Fiskeby³ power plant in Norrköping, Sweden is an example to be followed. The scheme owner wanted a maximum internal sound level of 80 dBA inside the powerhouse at full operation. The maximum allowed external sound level, at night, was set at 40 dBA in the surroundings of some houses located about 100 metres away.

To reach these levels of noise it was decided that all the components - turbines, speed increasers, and asynchronous generators - were bought in one package from one well-known supplier. The purchase contract specified the level of noise to be attained in full operation leaving the necessary measures to fulfil the demands to the manufacturer. The supplier adopted the following measures: very small tolerances in the gear manufacturing; sound insulating blankets over the turbine casing; water cooling instead of air cooling of the generator and a careful design of ancillary components. As well as the usual thermal insulation, the building was provided with acoustic insulation. Consequently, the attained level of noise varied between 66 dBA and 74 dBA, some 20 dBA lower than the average Swedish powerhouses. Having a single supplier, the issue of responsibility was eliminated.

The external noise level reduction was obtained by using vibration insulation of the powerhouse walls and roof. The principle for the vibration reduction system was to let the base slab, concrete waterways and pillars for the overhead crane be excited by vibration from the turbine units. The

other parts of the building such as supporting concrete roof beams and pre-cast concrete elements in the walls were supported by special rubber elements designed with spring constants giving maximum noise reduction. For the roof beams, special composite spring-rubber supporting bearings (Trelleborg Novimbra SA W300) were chosen. A similar solution was chosen for the pre-cast wall components. Once built, the sound emission from the powerhouse could not be detected from the other noise sources as traffic, sound from the water in the stream, etc. at the closest domestic building.

The underground powerhouse of Cavaticcio⁴, located about 200 m from the Piazza Maggiore, the historical heart of Bologna, has also merits in this respect. An acoustic impact study undertaken on Italian schemes showed an average internal level of about 85 dBA. The level of noise near the houses close to the proposed powerhouse was 69 dBA by day and 50 dBA by night. The regulations in force required that these values could not increase by more than 5 dBA during the day and 3 dBA during the night. The measures carried out to fulfil the requirements were similar to those undertaken in Fiskeby:

- Insulation of the machine hall, the most noisy room, from the adjacent rooms by means of double walls with different mass, with a layer of glass wool in between.
- Soundproofing doors.
- Floors floating on 15 mm thick glass wool carpets.
- False ceiling with noise deadening characteristics.
- Heavy trapdoors to the ground floor, fitted with soundproof counter trapdoors and neoprene sealing gaskets.
- Vibration damping joints between fans and ventilation ducts.
- Low air velocity (4 m/sec) ducts.
- Two silencers at the top and rear of the ventilation plant.
- Inlet and outlet stacks equipped with noise traps.
- Air ducts built with a material in sandwich (concrete, glass wool, perforated bricks and plaster).
- Turbine rotating components dynamic balanced.
- Water-cooled brushless synchronous generator.
- Precision manufactured gears in the speed increaser.
- Turbine casings and speed increaser casings strongly stiffened to avoid resonance and vibrations.
- Anchoring of the turbine by special anti-shrinking concrete to ensure the monolithic condition between hydro unit and foundation block.

- Turbine ballasting with large masses of concrete to reduce to a minimum the vibration's amplitude.

The underground ventilation has three main purposes: dehumidification of the rooms to ensure a correct operation and maintenance of the equipment, fresh air supply for the workers and removal of the heat generated by the various plant components. Even with the maximum volume of air circulation estimated at 7000 m³/hour the air velocity in the air ducts never exceeds 4 m/sec.

It is true that the two above examples are very particular ones but they are included here to show that everything is possible if it is considered necessary although the project may require a significant increase in the investment. It is also true that both examples concern low head schemes implying the use of speed increasers; a high mountain diversion scheme would permit the direct coupling of turbine and generator, so eliminating the component responsible for most of the vibrations.

7.4.2 Landscape impact

The quality of visual aspects is important to the public, who is increasingly reluctant to accept changes taking place in their visual environment. For example, a new condominium in our neighbourhood with an artificial beach built with sand coming from a submarine bed was rejected by a part of the population, even though, in many ways it would improve the environment including landscaping. The problem is particularly acute in the high mountain hydropower schemes or in schemes located in an urban area. This concern is frequently manifested in the form of public comments and even of legal challenges to those developers seeking to change a well-loved landscape by developing a hydropower facility.

Each of the components that comprise a hydro scheme - powerhouse, weir, spillway, penstock, intake, tailrace, substation and transmission lines - has potential to create a change in the visual impact of the site by introducing contrasting forms, lines, colour or textures. The design, location, and appearance of any one feature may well determine the level of public acceptance for the entire scheme.

Most of these components, even the largest, may be screened from view using landscaping and vegetation. Painted in non-contrasting colours and textures to obtain non-reflecting surfaces a component will blend with or complement the characteristic landscape. Creative effort, usually with small effect on the total budget, can often result in a project acceptable to all parties concerned: local communities, national and regional agencies, ecologists etc.

The penstock is usually the main cause of "nuisance". Its layout must be carefully studied using every natural feature - rocks, ground, vegetation - to shroud it and if there is no other solution, painting it so as to minimise contrast with the background. If the penstock can be interred, this is usually the best solution, although the operator has to meet some disadvantages in terms of maintenance and control. Expansion joints and concrete anchor blocks can then be reduced or eliminated; the ground is returned to its original state and the pipe does not form a barrier to the passage of wild life.

The powerhouse, with the intake, the penstock tailrace and transmission lines must be skilfully inserted into the landscape. Any mitigation strategies should be incorporated in the project, usually without too much extra cost to facilitate permit approval.

The examination of two schemes carefully designed to shroud their components will convey to potential designers a handful of ideas that should help to convince the environmental authorities that there is no place so environmentally sensitive as to prevent the development of a energy conversion process, so harmless and acceptable. The Cordinanes scheme in Picos de Europa (Spain) and the scheme on the river Neckar, located in the historical centre of Heidelberg (Germany) are considered below.

A small reservoir such as the one existing in Cordinanes (Photo 1) has some positive aspects. The existence of an almost stable level of water, and the tourist attractions (swimming, fishing, canoeing, etc.) that it provides counter balance its negative effects. Figure 1 shows a schematic view of the Cordinanes scheme.



Photo 7.1: Cordinanes

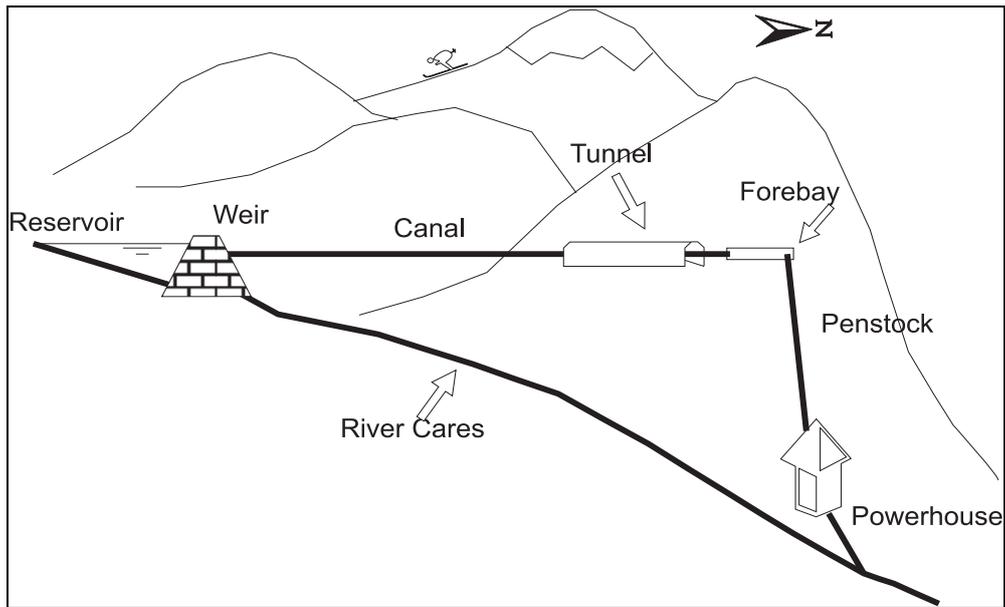


Figure 7.1: Schematic of Cordinanes scheme

The weir is a relatively airy concrete structure, but being 14 m high it is the most obtrusive component in the scheme (Photo 2). It needs to be so high because the water must reach the level of an old tunnel that, once rebuilt, will make part of the diversion canal. That is precisely the reason why the water level in the reservoir cannot vary by more than two metres and confers to the pond the character of a picturesque lake.



Photo7.2: Cordinanes Weir

And while referring to dams the Vilhelmina dam in Sweden, constructed of soil materials with an impervious core, should be mentioned (Photo3). The surface of the crest and the downstream slope

are protected against erosion by layers of large stones and boulders, which are embedded in reinforced concrete up to half their height. The downstream slope has a normal inclination of 1:3 except for a part, 40 m wide, where the inclination is 1:10. This design makes it possible for fish to pass up the dam enroute upstream. This dam has another environmental advantage since even with a small discharge it has the appearance of a natural rapid.



Photo 7.3: Vilhelmina dam in Sweden

An open canal built in reinforced concrete leaves, from the intake (Photo 4), with a section of 2 x 2.5 m and a length of 1335 m, entirely buried and covered by a layer of soil and vegetation.



Photo 7.4: Intake

Photo 5, Photo 6 and Photo 7 show a stretch of the canal in its three construction phases: land excavation reinforced concrete canal and finished canal with the recovered vegetal layer. The presence in the photographs of an electrical pylon - the transmission line between the villages of Posada de Valdeon and Cordinanes - confirms that it is the same site, because otherwise it would be impossible to identify the buried canal.



Photo 7.5: Construction phase – excavation



Photo 7.6: Construction phase – concrete canal



Photo 7.7: Construction phase – canal complete

Photo 8 and Photo 9 show how the entrance to the tunnel has been shrouded. In the first one the tunnel being rebuilt can be seen; in the second the canal connecting with the tunnel has been covered, as has the rest of the canal including the entrance to the tunnel. It is possible to enter the tunnel through the canal for inspection, after it is de-watered. In fact the tunnel already existed but was unfinished due to the lack of means to cross the colluvium terrain. It has now been rebuilt with a wet section of 2 x 1.80 m and with a 1:1000 slope, which conducts the water down to forebay, which is a perfect match with the surrounding rocks and has a semicircular spillway. From the forebay a steel penstock, 1.40 m diameter and 650 m long, brings the water to the turbines. In its first 110 m, the pipe has a slope close to 60°, in a 2.5 x 2 m trench excavated in the rock. The trench was filled with coloured concrete to match the surrounding rocks. A further trench was excavated in the soil and conceals the other 540 m, which as then covered by vegetation later on.

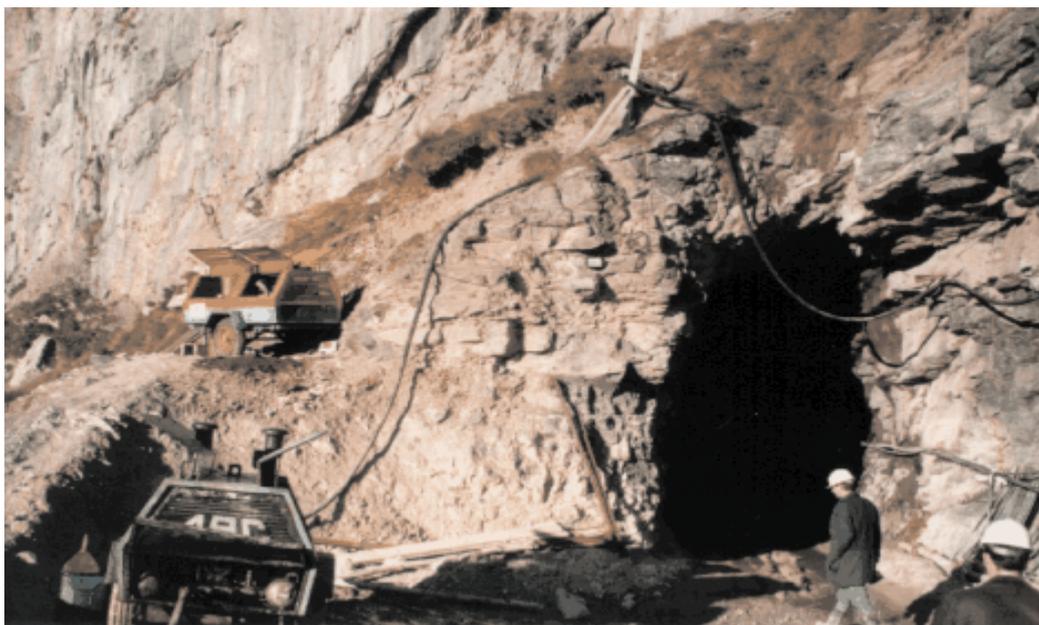


Photo 7.8: Tunnel entrance during construction



Photo 7.9: Tunnel entrance covered

Few metres before arriving at the powerhouse the pipe bifurcates into two smaller pipes that feed two Francis turbines of 5000 kW installed power each. The powerhouse (Photo10) is similar to the houses dotting the mountain. Its limestone walls, old roof tiles and heavy wood windows don't show its industrial purpose. In addition the powerhouse is buried for two thirds of its height also improving its appearance. To conceal the stone work of the tailrace a waterfall has been installed.



Photo 7. 10: Powerhouse

The substation is located in the powerhouse (Photo 11), in contrast with the usual outer substation (see photo 17), and the power cables leave the powerhouse over the penstock, under the tunnel and over the open canal. Close to the village where there are several transmission lines the power cables

come to the surface, to be buried again when the line transverses the north slope, a habitat of a very rare bird species - the "Urogayo".



Photo 7.11: Substation located in Powerhouse

The Neckar power plant (Photo 12) is located in the historical centre of Heidelberg⁵ and was authorised under the condition that it would not interfere with the view of the dam built in the past to make the river navigable. The powerhouse, built upstream of the dam, is entirely buried and cannot be seen from the riverbank. Figure 2 shows better than a thousand words the conceptual design, where stand two Kaplan pit turbines, and each one with a capacity of 1535 kW. The investment cost was of course very high - about 3760 ECU/installed kW.



Photo 7. 12: Nekar power plant

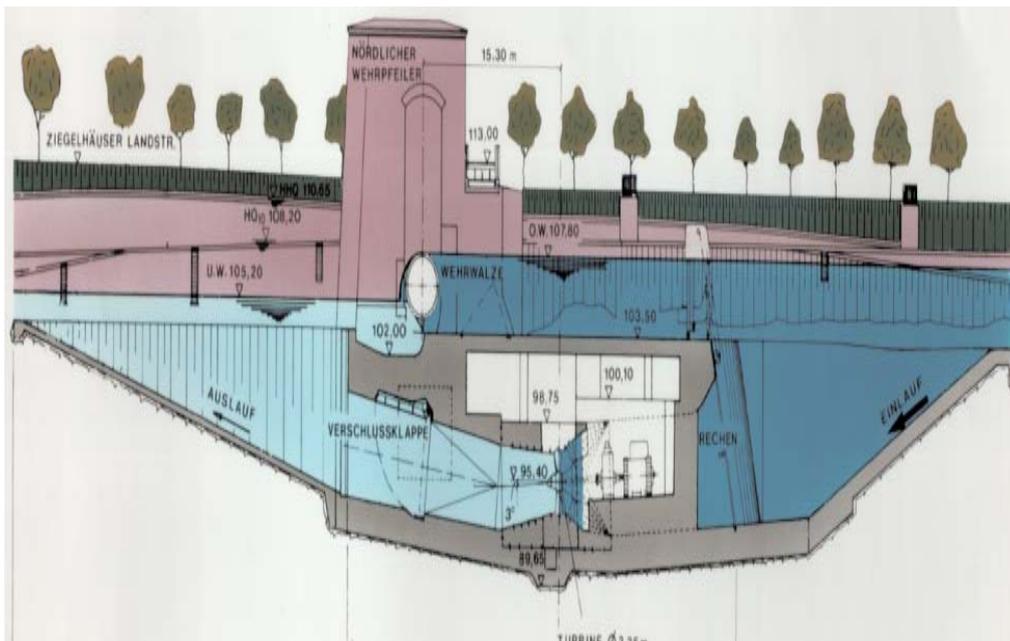


Figure 7.2: Neckar scheme in cross-section

7.4.3 Biological impacts

7.4.3.1 In the reservoir

Reservoir projects are very unusual in small hydropower although there are some schemes that store enough water to operate the turbine only during the periods of maximum electrical demand. Such operation is referred to as "peaking" or "peak-opping". In integral low head schemes, peaking can result in unsatisfactory conditions for fish downstream because the flow decreases when the generation is reduced. The lower flow can result in stranding newly deposited fish eggs in spawning areas. The eggs⁶ apparently can survive periods of de-watering greater than those occurring in normal peaking operation but small fish can be stranded particularly is the level fall is rapid.

7.4.3.2 In the streambed

A substantial proportion of small hydro plants are of the diversion type, where water is diverted from a stream or a lake into a hydroelectric plant perhaps kilometres from the diversion point to take advantage of the gain in head. The reduction in flow in the streambed between the point of diversion and the tailrace downstream of the powerhouse may affect spawning, incubation, rearing, and the passage of fish and of living space for adult fish.

Concerning peak operation – not typical for SHP – significant and frequent changes of discharge can ruin aquatic life because certain reaches of the riverbed are “flooded” and then dry up again periodically.

There is here a clear conflict of interest. The developer will maintain that the generation of electricity with renewable resources is a very valuable contribution to mankind, by replacing other conversion processes emitting greenhouse gases. The environmentalists will say, on the contrary, that the water diversion in the stream represents a violation of the public domain.

7.4.3.2.1 Reserved Flow

The formulas for calculation of reserved are many and their numbers tend to increase day by day. This demonstrates that no one has a good universally valid solution for reserved flow determination. In the following pages, some of the formulas subdivided by principle of calculation are provided. Each formula can only supply a value to be used as a reference for regulatory purposes.

A more complete survey on methods for calculating reserved flow can be found in the document prepared by ESHA within the Thematic Network on Small Hydroelectric Plants and available at the web address www.esha.be.

7.4.3.2.2 Methods based on hydrologic or statistic values

One method group refers to the average flow rate (MQ) of the river at a given cross section. The resulting reserved flow varies from 2,5 % of MQ for the Cemagref method applied in France to 60% for Montana (USA) method applied in the case where fisheries have a high economic importance. Typically, a figure of 10 % of the average flow is used for reserved flow.

A second method group refers to the minimum mean flow (MNQ) in the river. The reserved flow calculated when applying these methods varies from 20% (Rheinland-Pfalz, Hessen [D]) to 100% (Steinbach [A]) of MNQ.

A third method group refers to the prefixed values on the Flow Duration Curve (FDC). In this group a large variety of values are chosen as reference:

Q₃₀₀ (Swiss Alarm limit value method, Matthey and linearised Matthey),

Q₃₄₇ (German Büttinger method),

NMQ₇ (the lowest mean value of flow rate in the seven months with the higher natural discharges),

NMQ_{Aug} (the minimum mean flow in August), Q_{84%}, Q₃₆₁, Q₃₅₅ and so on.

7.4.3.2.3 Methods based on physiographic principles

These methods usually refer to a constant specific reserved flow (l/s/km² of catchment area). In addition, in this case the values of reserved flow suggested are highly variable. For example, a figure of 9.1 l/s/km² is required in the USA where rivers have an excellent abundance of fish down to 2 l/s/km² of the crystalline catchments in the Alps.

Advantages of these methods

- Easily applicable under the presupposition of good basic data,
- Natural fluctuation could be eventually taken into account,
- Supply of a rough evaluation of the economic energy production,
- Methods based on MNQ or NNQ should be preferred,
- No recognisable ecological background.

Disadvantages

- Academic formulas which supply rigid values,
- NNQ could be easily underestimated,
- No consideration for hydraulic parameters of flow,
- Effect of tributaries or abstractions in the diversion section and the diversion length no taken into account,
- Economic operation of small hydroelectric plants could be hardly affected,
- Methods not suitable for many typologies of rivers and doubtful transferability from river to river.

7.4.3.2.4 Formulas based on velocity and depth of water

In this group of methods, we also have a great variation of values suggested for the typical parameters. Water velocity can range from 0,3 m/s (Steiermark method) to 1,2-2,4 m/s (Oregon method) and water depth must be higher than 10 cm (Steiermark method) to 12-24 cm (Oregon method).

Other formulas falling into this group suggest a reserved flow referred to river width (30-40 l/s per meter of width) or to the wetted perimeter (in case of reserved flow the wetted perimeter must be at least 75% of the undisturbed flow).

Advantages of this method

- Main flow characteristics are maintained,
- The shape of profile can be included in the calculation,
- Individual river approach,
- No hydrological data needed,
- Only indirect and general relations with ecological parameters,
- Suitable to evaluate the consequences on energy production economics.

Disadvantages

- Slope and natural water pattern don't enter in the calculation,
- Diversion length and effect of tributaries or abstractions stay unconsidered,
- Without river re-structuring measures, in wide rivers these methods give very high values of reserved flow,
- Reasonable use only for particular kind of depleted reach,

- In mountain torrents give unrealistic values of threshold water depth,
- Suitable only for particular typologies of rivers, transferability doubtful.

7.4.3.2.5 Methods based on multi-objective planning taking into consideration ecological parameters

Due to the high specificity of these methods, which is hard to condense into a word, a short description is given.

MODM [Multi Objective Decision Making]

The determination of reserved flow results from a model, which considers both ecological and economic objectives. The solution to be chosen must have the best compromise value of both kinds of parameters. The following measured variables are used as parameters:

- Opportunity for regular work (economy)
- Smallest maximum depth (diversity of species and individual size)
- Highest water temperature (change of thermal conditions)
- Smallest oxygen contents (water quality)

Dilution ratio

The necessary discharge must be at least 10 times of the introduced, biologically cleaned discharge. The velocity can't fall below 0,5 m/s.

Flow parameters

The effects of reserved flow are measured with the help of a model. From this necessary corrections and/or construction measures in the diversion area can be derived.

PHABSIM

This method is based upon the knowledge of the combination of the parameters - water depth, flow velocity, temperature and sediment preferred by the majority of fish species. Under these presuppositions have been defined, both technically and with respect to the desired spectrum of fish species, the reserved flow necessary can be calculated.

Habitat Prognoses Model

In order to limit the expenditure-intensive investigations for the determination of the reserved flow conditions in difficult cases, this model was developed. The model operates based on fewer aggregated-morphologic parameters, the reserved discharge conditions relevant for the biogenesis can be prognosticated computationally. A "minimum ecological discharge" and an "economic energy" threshold value are determined. The final residual flow suggested would be a function of both these values, whereby the following facts are considered. It applies a degradation prohibition with respect to the current conditions. The residual flow suggestion may not exceed the minimum ecological discharge.

Reserved flow is the economic energy threshold value or 4% of the small hydroelectric plant flow rate. Reserved flow must be 5/12 of MNQ as a maximum.

Habitat Quality Index (USA)

This model is based on multiple regression. It links the so-called bearing capacity for Salmonids in a stretch of river with a set of ecological parameters. It requires the collection of a great number of different environmental data necessary to calculate the biomass of Salmonids, which can live in the identified stretch of river.

Pool Quality Index

This model is derived from the HQI method, it's based on the maximisation of the hydraulic diversity i.e. the higher the number of pools in a torrent, and the lower the reserved flow is. Depending on the percentage of pools the method supplies the following values for reserved flow to be compared with values obtained by methods described in 7.4.3.2.2, 7.4.3.2.3 and 7.4.3.2.4:

- 7 – 9 % of MQ
- 50 – 70 % of Q_{355}
- 3.6-4,3 l/s/km²

Definition of the dotation water delivery through dotation attempts

The concept of “dotation” corresponds to the artificially regulated flow rate at a certain time and in a certain cross section to guarantee a required amount of water in a different cross section of the same river.

This method is based on the determination of the reserved flow conditions in combination with the simulation of potential future conditions in the diverted section of the river.

The method represents the connection with ecologically relevant parameters with available realisations concerning preference ranges and/or preference curves. It is described as rather simple and economical method. It presupposes however the possibility of measuring small discharges in the future diversion section of the river. With existing plants, this is simple - in all other cases low-water periods must be used for these measurements and will almost certainly require extrapolation.

Advantages of this method

- Site specific flow observations
- Taking into account of hydrological, hydraulic, ecological, and meteorological quantities
- Consideration of both ecological and economical parameters

Disadvantages

- Methods expensive in data collecting and mathematical computing
- Suitable only for particular typologies of rivers, transferability doubtful.

Example of application of different methods using the following criteria

A =	120 km ²	Q ₃₀₀ =	1.90 m ³ /s
Average river width:	20 m, approx. rectangular	Q ₃₄₇ =	1.60 m ³ /s
Average river slope:	2.3%	Q ₃₅₅ =	1.38 m ³ /s
MQ =	2.33 m ³ /s	Q ₃₆₁ =	0.37 m ³ /s
		NMQ =	0.15 m ³ /s

Figure 7.3: Example Flow Duration Curve

Table 7.3: Methods based on hydrologic or statistic values

METHOD	DESCRIPTION	RESERVED FLOW (L/S)	METHOD	DESCRIPTION	RESERVED FLOW (L/S)
10% MQ		233	Rheinland-Pfalz	$0,2 - 0,5 \cdot Q_{365}$	30-75
Lanser	5-10% MQ	116-233	Hessen	$0,2 - 0,9 \cdot Q_{365}$	30-135
Cemagref	2,5-10% MQ	58-233	Q ₃₆₁		370
Steinbach	Q ₃₆₅	150	Alarm limit	0,2 Q ₃₀₀	380
Baden-Württemberg	$1/3 \cdot Q_{365}$	50	Büttinger	Q ₃₄₇	1.600

Table 7.4: Methods based on physiographic principles

METHOD	DESCRIPTION	RESERVED FLOW (L/S)	METHOD	DESCRIPTION	RESERVED FLOW (L/S)
USA	2,6-9,1 l/s/km ²	312-1.092	Tirol	2-3 l/s/km ²	240-360
Lombardy	2,88 l/s/km ²	346			

Table 7.5: Formulas based on velocity and depth of water

METHOD	DESCRIPTION	RESERVED FLOW (L/S)	METHOD	DESCRIPTION	RESERVED FLOW (L/S)
Steiermark	0,3-0,5 m/s	80-290	Oregon	1,2-2,4 m/s	2600-15000
Oberösterreich	hw ≥ 20 cm	7150	Steiermark	hw ≥ 10 cm	2290
Miksch	30-40 l/s/m _{width}	600-800	Tirol	hw ≥ 15-20 cm	4450-7150

Table 7.6: Methods based on multi-objective planning taking into consideration ecological parameters

METHOD	DESCRIPTION	RESERVED FLOW (L/S)	METHOD	DESCRIPTION	RESERVED FLOW (L/S)
PQI	7 – 9 % MQ	163-210	PQI	50–70% Q ₃₅₅	690-966
Oberösterreich	3,6-4,3 l/s/km ²	432-516	Steiermark	hw ≥ 10 cm	2290

The tabled examples show a large variation and underline how difficult the applying of these methods can be is when calculating the reserved flow to be released downstream of a water diversion work. In particular the application of the formulas based on velocity and depth of water leads to unreasonable values.

In this context, it makes sense to think about river restructuring methods to reduce the amount of reserved flow. This approach allows the double opportunity of achieving a better environmental efficiency of the water released (water depths and velocities suited to the ecosystem requirements) and the increase in energy production from a renewable source.

It must be underlined that if any of the biological methods (for defining the reserved flow value) are implemented, then there is a possibility for the developer to decrease the level of the required reserved flow through modifying the physical structure of the streambed. Well-known measures of river rehabilitation and river restructuring perform perfectly within these efforts. Measures such as growing trees on the riverbanks to provide shadowed areas, gravel deposits in the streambed to improve the substratum, reinforcement of the riverside through shrubs to fight erosion, etc can all assist. The investment necessary for these measures is most likely compensated very quickly by a significant decrease of reserved flow.

Figure 4 (reproduced from a paper by Dr. Martin Mayo) illustrates the kind of coverage and refuge against the flow, sunshine and danger that can be given to vertebrates and invertebrates by both natural and artificial elements. The existence of caves and submerged cornices provides a safe refuge against the attacks of a predator. In addition, the riverine vegetation close to the water provides shade used by fish to prevent overheating and provides concealment in face of terrestrial predators. (It must be said that the most dangerous terrestrial predator is the freshwater fisherman). All these elements contribute to the concept that in the WUW (Weighted Useful Width) APU method is known as refuge coefficient. By increasing its importance, the required value of the reserved flow may be diminished. In that way, a better protection of the aquatic fauna can be combined with a higher energy production.

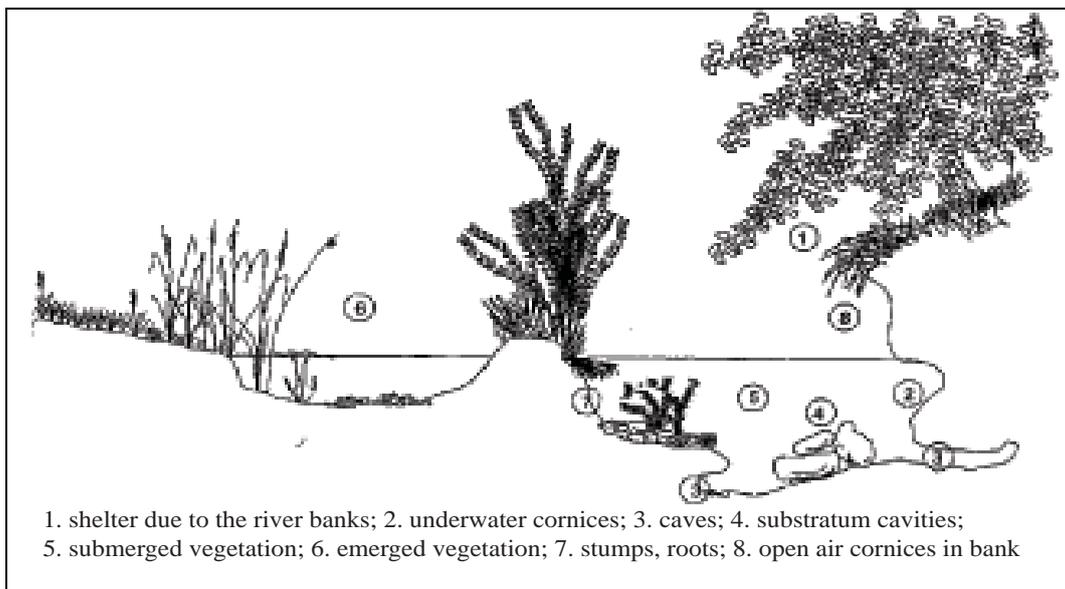


Figure 7.4: Cross-section of a river bed

Just for demonstration purposes – the relation between environmental flow and riverbed morphology looks like the following graph:

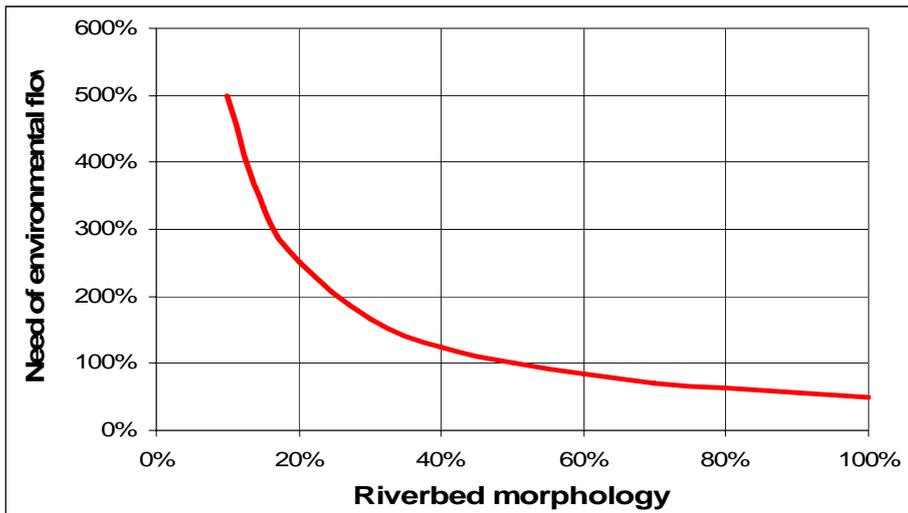


Figure 7.5: Relation between environmental flow and riverbed morphology

Out of the many possible types of works it’s worth mentioning the creation of pools for fish breeding, meandering low water riverbeds to increase velocities and depths in the case of low flow, modification of the slope to increase the water depths concentrating in small waterfalls or ramps (30-40 cm) the consequent sudden slope changes.

The difficulty with these types of works is in making the modification permanent, i.e. resistant to floods and natural riverbed dynamics that should not be underestimated.

A more complete survey on the effects of additional parameters on reserved flow (slope, tributaries, river structure and so on) can be found in the document prepared by ESHA within the Thematic Network on Small Hydroelectric Plants and available at the web address www.esha.be.

7.4.3.2.6 Fish passes (upstream fish)

Anadromous fish are those, which spawn in fresh water but spend most of their lives in the ocean. Catadromous fish are those that spawn in the ocean, reach adulthood in fresh water and require passages at dams and weirs. A great variety of fish pass designs are available, depending on the species of fish involved. Otherwise, freshwater fish seem to have restricted movements.

Upstream passage technologies are considered well developed and understood for certain anadromous species including salmon. According to OTA 1995 (Office of Technology Assessment in the U.S.A.) there is no single solution for designing upstream fish passageways. Effective fish passage design for a specific site requires good communication between engineers and biologists, and thorough understanding of site characteristics. Upstream passage failure tends to result from a lack of adequate attention to operation and maintenance of facilities.

The upstream passage can be provided for through several means: fish ladders, lifts (elevators or locks), pumps and transportation operations. Pumps are a very controversial method. Transportation is used together with high dams. These highly technical approaches are rather unusual in small hydropower schemes. A great variety of constructions and design of fish bypass systems is the main approach in SHP. Site and species-specific criteria and economics would determine which solution is most appropriate.

Fish bypass systems (natural-like creek without steps, pool and weir, Denil-passes, vertical slots, hybrid etc.) can be designed to accommodate fish that are bottom swimmers, surface swimmers or orifice swimmers. However, not all kinds of fish will use ladders. Fish elevators and locks are favoured for fish that does not use ladders

The most common fish pass is the weir and pool fish pass, a series of pools with water flowing from pool to pool over rectangular weirs. The pools then play a double role: provide rest areas and dissipate the energy of the water descending through the ladder. The size and height of the pools must be designed as a function of the fish to be handled. The pools can be supported by:

- Baffles provided with slots, so that both fish and bedload, pass through them
- Baffles provided with bottom orifices large enough to allow fish to pass
- Baffles provided both with vertical slots and bottom orifices

Pools separated by baffles with bottom orifices only do not have practical interest because are limited to bottom orifice fish swimmers. Salmon do not need them because they can jump over the baffle itself, and shads, for instance, are not bottom swimmers. The system of rectangular weirs (Figure 6) is the oldest one, but presents the inconvenience that when the headwater fluctuates the fish pass flow increases or decreases, resulting in a fish pass with too much or too little flow.

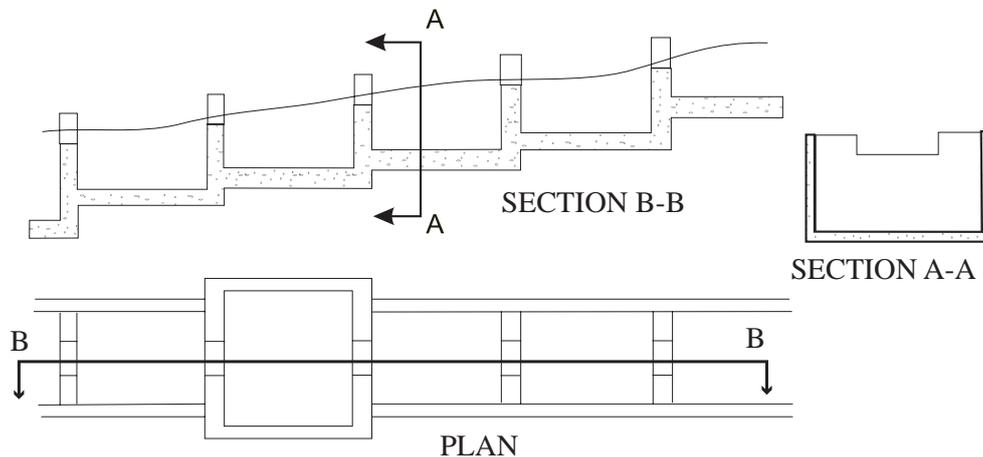


Figure 7.6: System of rectangular weirs

Moreover this type of ladder will not pass bedload readily and must be designed with bottom orifices for this purpose. Photo 13 shows one of these ladders with a rustic construction designed for salmon checking on a river in Asturias (Spain).



Photo 7.13: Fishpass of rustic construction

Photo 14 illustrates a fish ladder with vertical slots and bottom orifices that usually yields very good results. The shape and disposition of the baffles are shown in perspective in Figure 5 the width of the pools, for lengths varying between 1.8 and 3.0 m, varies from 1.2 m to 2.4 m. The drop between pools is in the order of 10-30 cm. Shads require a drop not bigger than 25 cm. In principle size and drops depend on the species the system is built. Computer programs⁷ optimise the width and length of pools, the drop between pools and the hydraulic load.



Photo 7.14: Fishpass with vertical slots

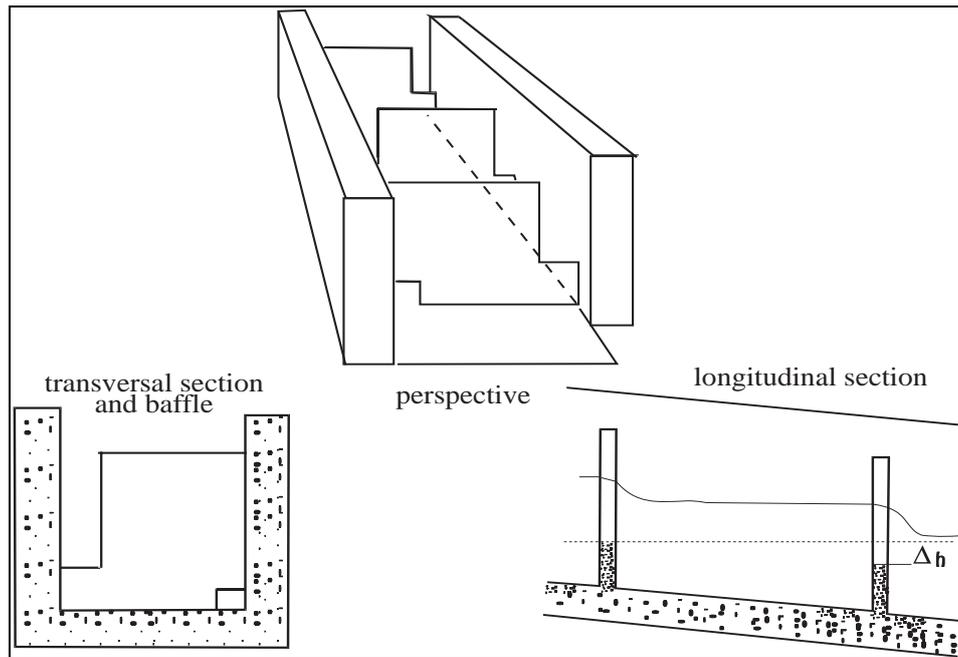


Figure 7.7: Fishpass baffles in section

The vertical slotted fish pass (Figure 8) is very popular in the U.S.A. but not well known in Europe⁸. Through the baffle's vertical slot passes both fishes and bedload. A standard model has pools 2.5-m wide, 3.3 m long with a slot 30 cm wide. Supporters of this type of ladder praise its hydraulic stability even with large flow variations.

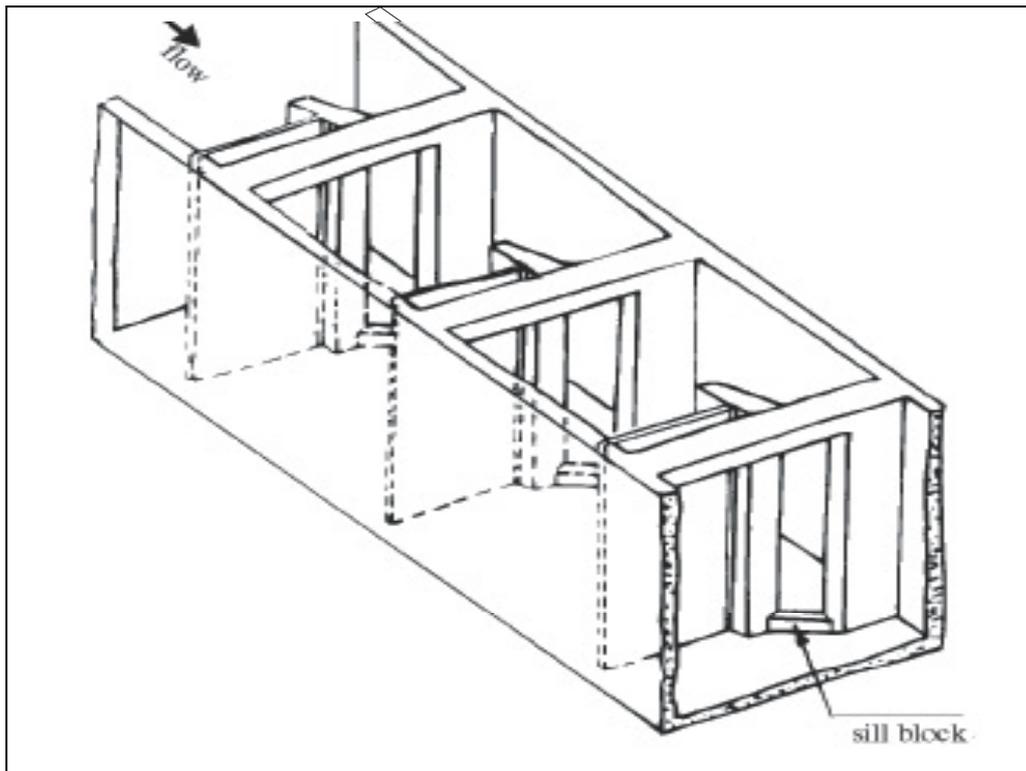


Figure 7.8: Vertical slotted fish pass

The Denil fish pass (Photo 15) is steep and consists of narrow chutes with vanes in the bottom and sides as illustrated in Figure. These vanes dissipate the energy providing a low-velocity flow through which the fish can easily ascend.



Photo 7.15: A Denil Fishpass

This characteristic allows a Denil to be used with slopes up to 1:5. They also produce a turbulent discharge that is more attractive to many fish species than the discharge from pool-type fish passes, and are tolerant of varying water depths. The ladder must be provided with resting areas after approximately 2-m. gain of elevation.

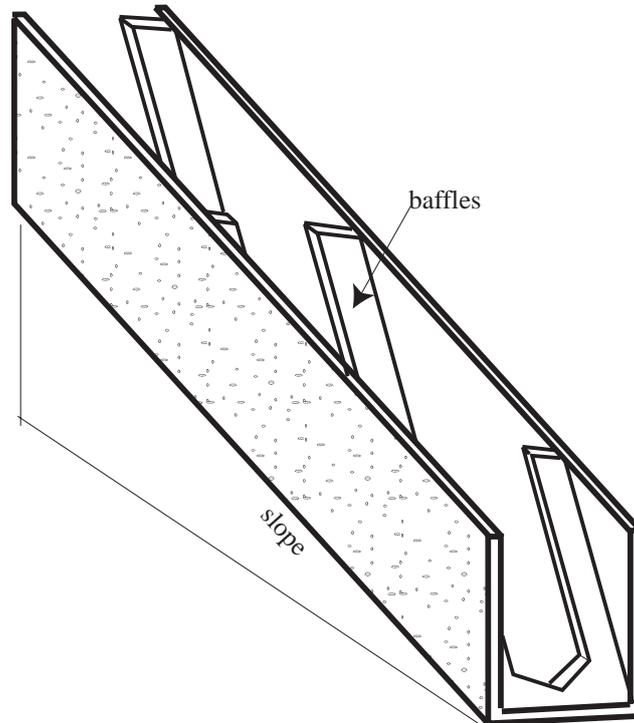


Figure 7.9: Chutes and Vanes of Denil Fishpass

The Borland lock (Figure 10) is a relatively cheap solution to transfer fish from the tailrace to the forebay in a medium dam. The fish climb a short fish ladder to the bottom chamber. Then the entrance to the bottom chamber is closed and the shaft rising from it to the top of the dam becomes filled with the water flowing down from the forebay through the top chamber. Once filled, the fish that are attracted by this flow are close to the forebay level into which they can swim.

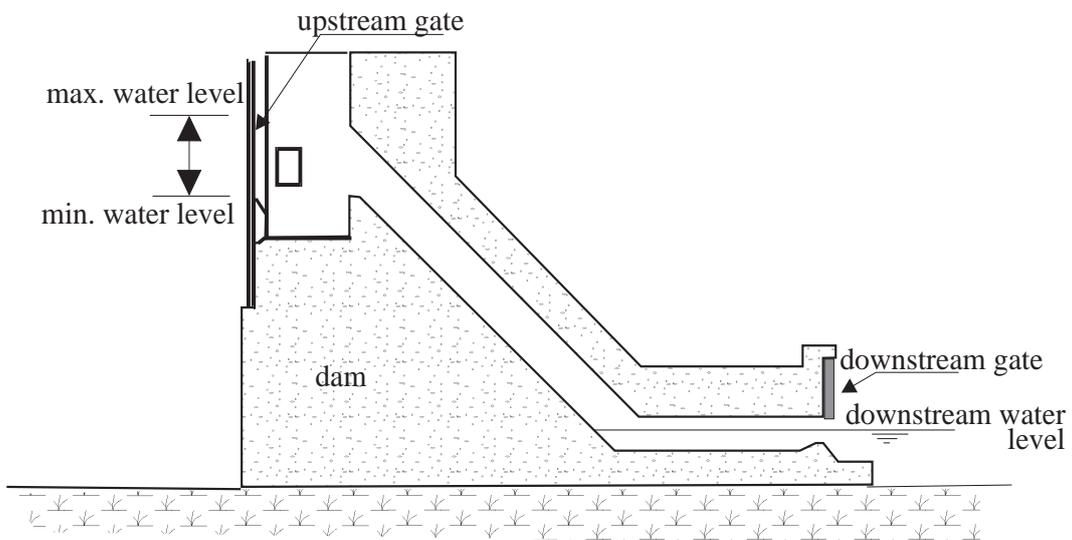


Figure 7.10: Section through Borland Lock

In higher dams, the best solution is to install a lift specifically designed for this purpose. EDF in France has a wide experience with these lifts. The Golfech lift for instance when it was commissioned in 1989 made it possible to pass twenty tonnes of shad (about 66 000 individuals) that were blocked at the base of the dam. Otherwise, the only possible solution is to trap the fish at the base and transport them safely upstream. These devices are discussed in reference³. All that is needed is a small fish pass to bring the fish from the tailrace to the trap. There, by mechanical means the fish are concentrated in a trolley hopper, and loaded onto a truck. Eventually the trolley hopper carries them directly over the dam's crest via a cableway and they are discharged into the reservoir.

The most important element of a fish-passage system, and the most difficult to design for maximum effectiveness, is the fish-attraction facility. The fish-attraction facility brings fish into the lower end of the fish-passage and should be designed to take advantage of the tendency of migrating fish to search for strong currents but avoid them if they are too strong. The flow must therefore be strong enough to attract fish away from spillways and tailraces. The flow velocities at the entrance of the fish pass vary with the type of fish being passed, but for salmon and trout, velocities from 2 to 3 m/s are acceptable. A lack of good attraction flow can result in migration delays as the fish become confused and mill around looking for the entrance. If necessary, water must be pumped into the fish pass from the tail water areas, but usually enough water can be taken at the upstream intake or forebay to be directed down the fish pass. When addressing salmon an attraction flow should be maintained between 1 and 2 m/s. If the water is too cold (less than 8°) or too hot (above 22°) then the speed must be decreased as the fish become lazy and do not jump. Water can be injected just at the entrance of the fish pass avoiding the need to transverse all its length (Figure 11)

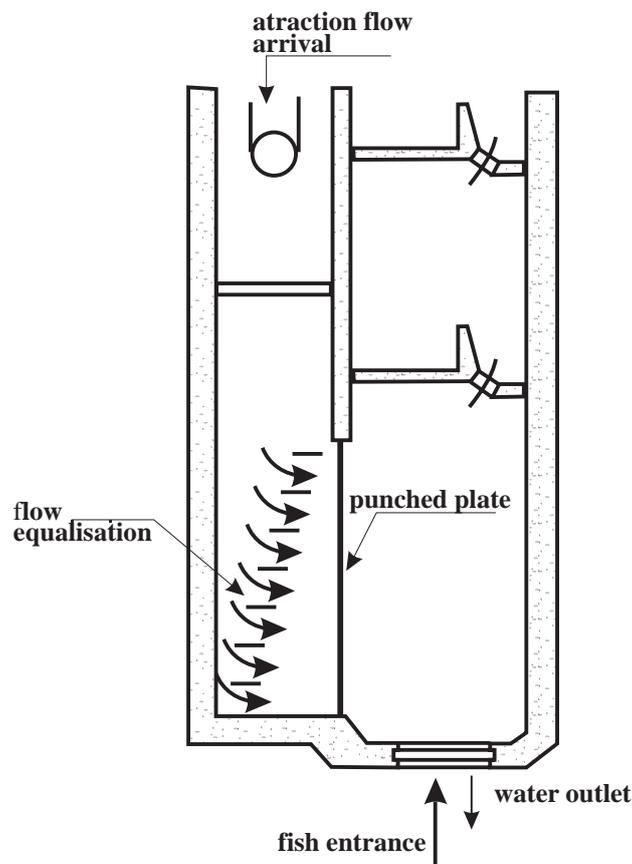


Figure 7.11: Water attraction facility

The entrance to the fish-passage should be located close to the weir since salmon tend to look for the entrance by going around the obstacle. In low-head integrated schemes, the entrance should be in the bank close to the powerhouse as illustrated schematically in Figure 10 and shown in Photo 16.

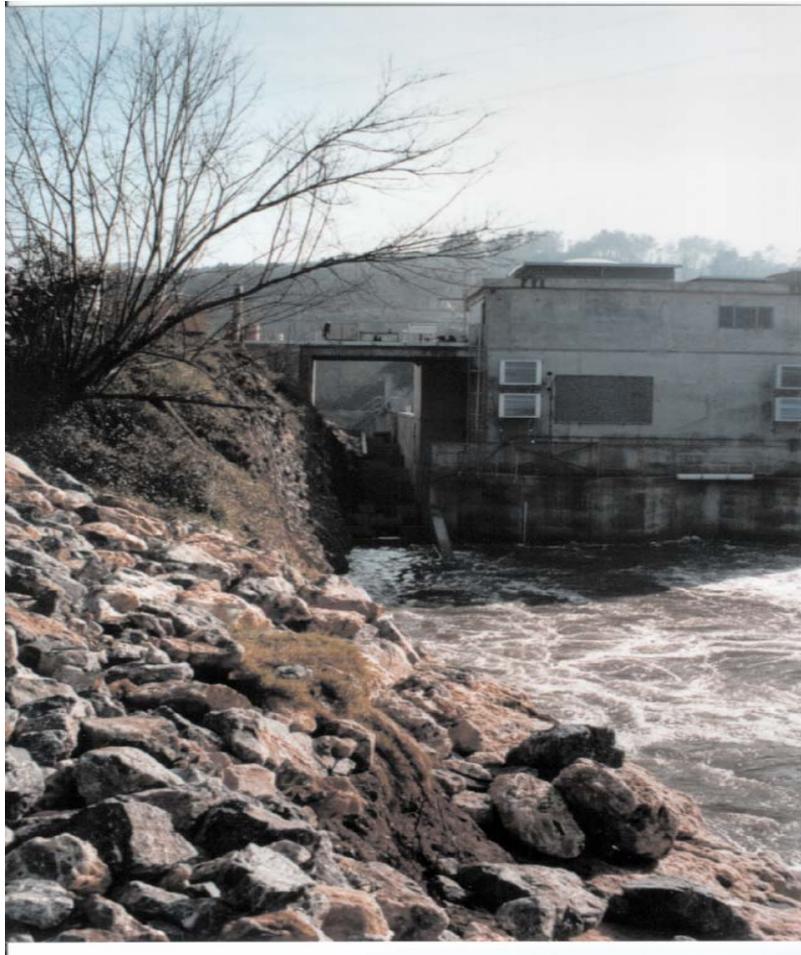


Photo 7.16: Powerhouse and fishpass in the left

The upstream outlet of the fish-passage should not be located in an area close to the spillway, where there is a danger of being sent back to the base of the dam, or in an area of dead circulating waters where the fish can get trapped. Fish-passages must be protected from poachers, either closing it with wire mesh or covering it with steel plates.

The use of fish pumps for fish passage at dams is controversial and largely experimental. This technology is relied upon in aquaculture for moving live fish. Several pumps are in the market and new ones are being developed. Pumping of the fish can lead to injury and de-scaling because of crowding in the bypass pipe.

7.4.3.2.7 Fish passes (downstream fish)

In the past downstream migrating fish passed through the turbine. The fish-kill associated with this method varies from a few percent to more than 40% depending on the turbine design and more specifically on the peripheral speed of the runner. In a Francis turbine increasing the peripheral runner speed from 12 m/sec to 30 m/sec increases the percentage mortality from 5% to 35%.

Francis turbines, due to their construction characteristics cause greater mortality than Kaplan turbines. Bulb turbines reduce mortality to less than 5%⁹.

Apparently, head is not a decisive factor. A turbine working at a head of 12 meters produces the same mortality as one working at a head of 120 m. The elevation of the runner above tail water is a very important factor, quite apart from the effect of cavitation. The more efficient a turbine is, the less mortality it produces. A turbine working at rated capacity consequently causes less mortality than one working at partial load. Mechanical injuries by collision against solid bodies - guide vanes or turbine blades, exposure to sub-atmospheric pressures and shear effects produced at the intersections of high velocity flows in opposite directions are the main causes of mortality.

Recently an innovative self-cleaning static intake screen, that does not need power, has been used for fish protection. The screen uses the Coanda¹⁰ effect, a phenomenon exhibited by a fluid, whereby the flow tends to follow the surface of a solid object that is placed in its path. In addition, the V shaped section wire is tilted on the support rods, (Figure 12) producing offsets, which cause a shearing action along the screen surface.

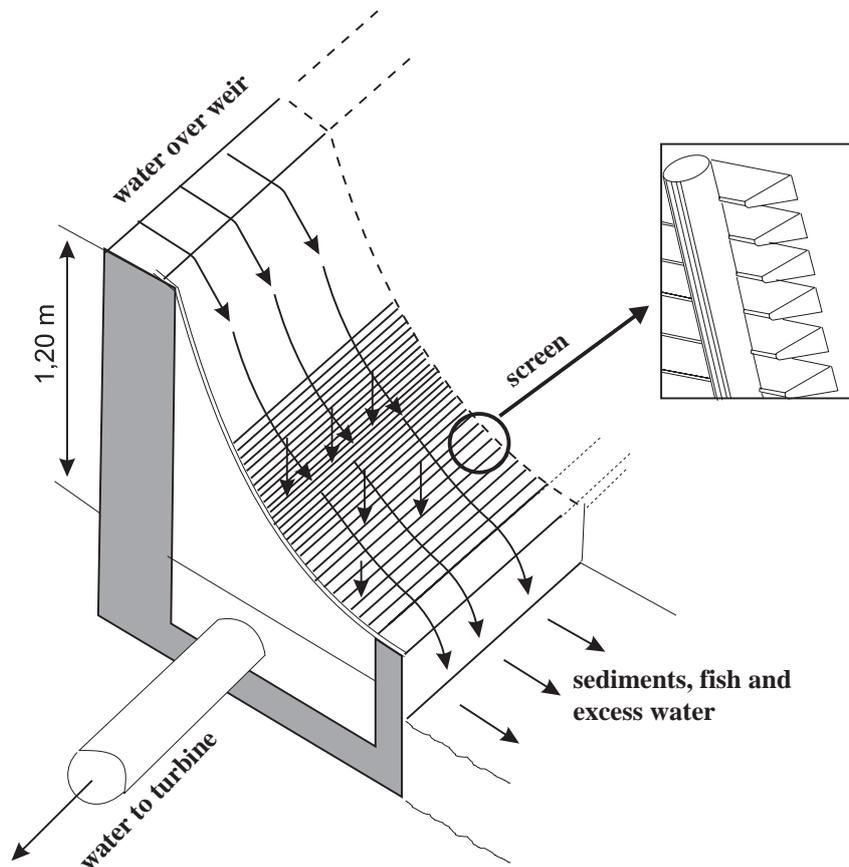


Figure 7.12 Coanda screen schematic

The water flows to the collection system of the turbine through the screen slots, which are normally 1 mm wide. Ninety per cent of the suspended solid particles, whose velocity has been increased on the acceleration plate, pass over the screen thus providing excellent protection for the turbine. Aquatic life is also prevented from entering the turbine through the slots. In fact, the smooth surface of the stainless steel screen provides an excellent passageway to a fish bypass. The screen can handle up to 250 l/s per linear meter of screen. A disadvantage of this type of screen is that it requires about 1 to 1.20 m. of head in order to pass the water over the ogee and down into the

collection system. This can be uneconomic in low head systems. Photo 17 shows a Coanda screen¹¹.

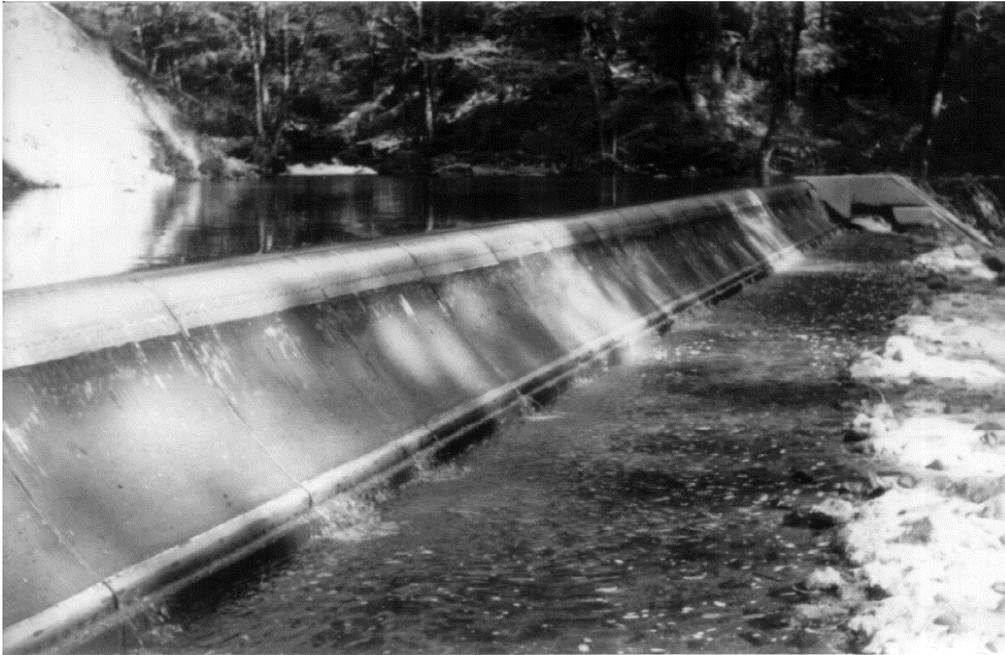


Photo 7.17: Coanda Screen in situation

7.4.3.2.8 Behavioural guidance systems

Behavioural guidance systems and a variety of alternative technologies to divert or attract downstream migrants have been the recent object of studies by the Electric Power Research Institute (EPRI). These technologies include strobe lights for repelling fish, mercury lights for attracting fish, a sound generating device known as "hammer" for repelling fish as well as quite a number of electrical guidance systems. It has not yet been demonstrated that these responses can be directed reliably. Behavioural guidance techniques are site and species specific and it appears unlikely that behavioural methods will perform as well as fixed screens over a wide range of hydraulic conditions¹².

Behavioural screens operate by using the natural response of fish to a stimulus to deflect the fish away from the stimulus. A number of behavioural systems have been tested and acoustic systems have been found to be the most effective systems. For fish to be repelled by a sound, the level of the sound must be high enough to elicit a reaction, taking account of background noise. The background noise issue is important, especially where acoustic systems are deployed near to underwater machinery such as pumps and turbines. The signal types that have proved most effective in all applications are based on artificially generated waveforms that rapidly cycle in amplitude and frequency content, thus reducing habituation. A human equivalent would be being made to stand near to a wailing police or ambulance siren. It simply gets uncomfortable, so you move away! Deflection is usually the best course of action, as the fish are moved swiftly from the source of danger (e.g. water intake) into a safe flow. The BAFF (Bio Acoustic Fish Fence) system produces a "wall of underwater sound" by using compressed air to generate a continuous bubble curtain into which low frequency sound (varying between 50 and 500 Hertz) is injected and entrapped. Although well defined lines of high level sound (at least 160 decibels) are generated within the bubble curtain, the noise levels are negligible a few meters away from it. By restricting

the sound curtain to a small area, the system allows fish to act normally throughout the remainder of the reservoir or river. Figure 13 illustrates the disposition of a system of underwater acoustic transducers, which transmit their sound into a rising bubble curtain to create a wall of sound to guide fish out of the turbine passage.

As manifested by Mr. Turpenney of Fawley Aquatic Research Laboratories Ltd U.K. "the disadvantage of behavioural screens over conventional mechanical screens is that they do not exclude 100% of fish, whereas a mechanical screen of sufficiently small aperture will do so. Typical efficiencies for behavioural barriers range from 50% to 90%, depending upon type and environmental and plant conditions. Most fish penetrating the barrier are likely to go on to pass through the turbine, thereby putting them at risk of injury."

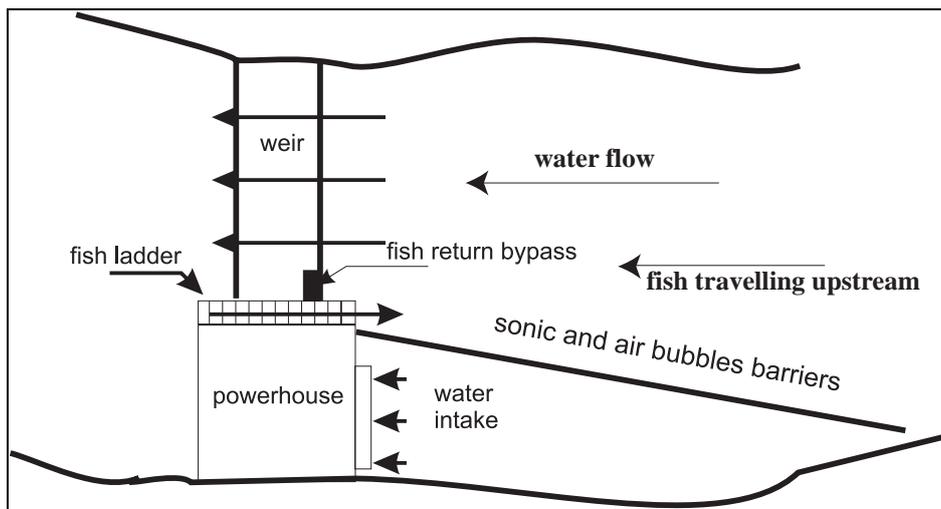


Figure 7.13: Bio-Acoustic Fish Fence

Bypass routes must be provided to allow fish to move from the area in front of a physical barrier back to the river.

The screens located at the intake entrance do not need any return conduit because fish are entrained by the water flow and return to the river usually over the spillway. This is of course less dangerous than the turbines, although it also can be damaging. Surprisingly, high spillways are not necessarily more dangerous for fish than low ones. Terminal velocity, as demonstrated by dropping salmon from helicopters into a pond, is reached after about 30 meters of fall, and remains constant thereafter. Eicher mentions an experimental ski-jump spillway, which throws the fish out in free fall to a pool 80m below with a mortality rate reduced to virtually zero.

When the screen is located in the intake downstream of the entrance, a bypass returning the fish to the river is needed. According to behavioural characteristics fish migrating downstream cannot be expected to swim back upstream to find the entrance. This must therefore be located at the downstream end of the screen, assuming the screen is inclined in the direction of the flow. Fish are frequently reluctant to move into small size entrances. A minimum bypass entrance of 45cm is recommended, especially when dealing with juvenile salmonids. It would be preferable that the entrance width could be adjustable by the use of fabricated metal inserts to reduce the size of the opening. The bypass entrance design should provide for smooth flow acceleration into the bypass conduit with no sudden contractions, expansions or bends.

To return fish from the bypass entrance back to the river, fully close conduits or open channels can be used. Fish do not like to enter in conduits with abrupt contrast in lighting. Open channels are better suited for that role. Internal surfaces should be very smooth to avoid fish injury. High density polyethylene and PVC are excellent materials for bypass conduits.

Abrupt changes in section should be avoided due to their associated turbulence and pressure changes. In full flow conduit pressures below atmospheric should be avoided because they can injure or even kill fish. Air entrainment in a full flow conduit generates hydraulic turbulence and surging thus avoiding gas super saturation in the water, which can be detrimental to fish. Conduit discharge velocities should not be too high (relative to the typical velocities in the outfall) so as to create shear forces that can injure fish. Velocities close to 0.8 m/sec are recommended.

7.4.3.3 In the terrain

Open canals may sometimes be an obstacle to the free passage of animals. To avoid this, nowadays open canals are entirely buried and even repopulated with vegetation so they do not represent any barrier. In contradiction, the burial of the water conveyance structure is said to be a loss of aquatic habitat for several purposes. It is reported that sometimes animals may fall into an open canal without any chance to get out due to a rectangular cross section. Certain ladder constructions may serve effectively at rather low cost. Other construction work in connection with SHP will not be an ecological impact worth mentioning.

7.4.3.4 Trashrack material

Almost all small hydroelectric plants have a trash rack cleaning machine, which removes material from water in order to avoid it entering plant waterways and damaging electromechanical equipment or reducing hydraulic performance. Each year tons of material (typically plastic bags, bottles, cans and other kinds of things man and as well as carcasses, leaves and natural detritus also found in the water) are removed from the water stream.

In many countries, once a thing, including organic material (leaves, branches and so on) is removed from the main stream, it becomes automatically waste material. When this is the case it cannot be thrown back into the water but must be properly disposed often at very high costs.

With this being the case, it is clear that small hydroelectric plants play a fundamental role in cleaning the river environment. This benefit to the river is often unacknowledged but clearly represents a positive impact by the small hydroelectric plants and it should be duly taken into account. Suitable support measures should be undertaken to reduce the economic burdens on small hydroelectric plants operators regarding this matter (e.g. by reducing the waste disposal fees or allowing for different treatment between organic and not-organic material).

7.5 Impacts from transmission lines

7.5.1 Visual impact

Above ground transmission lines and transmission line corridors can have a negative impact on the landscape. These impacts can be mitigated by adapting the line to the landscape, or in extreme cases burying it.



Photo 7.18 Visual impact of outdoors substation

The optimal technical and economic solution for a transmission line routing is that which will often create the more negative aesthetic impacts. To achieve optimal clearance from the ground the pylons are placed on the top of the hills, constituting a very dominating element of the landscape. A minimum of bends in the route will reduce the number of angle and ordinary pylons and therefore reduce its cost. Aesthetically neither a high frequency of bends, nor straight routes that are made without consideration for the terrain and landscape factors are preferred.

In sensitive mountain areas where schemes are developed, transmission lines can dominate the landscape and therefore influence the beauty of the scenario. It must be remarked that transmission lines exist even without the existence of hydropower schemes. Villages even if they are high in the mountain require electricity to make life liveable, and electricity, unless generated by photovoltaic systems, requires transmission lines. It is true that with a right siting of the lines in relation to larger landscape forms and a careful design of the pylons the impact can be relatively mitigated. Other times, as in Cordinanes, the transformer substation and transmission lines are concealed from public view and the situation much improved, but it is an expensive solution that only can be offered if the scheme is profitable enough.

7.5.2 Health impact

In addition to the visual intrusion, some people may dislike walking under transmission lines because of the perceived risks of health effects from electromagnetic fields. Apart from the fact that this risk is only perceived in high voltage transmission lines, and never is the case in a small hydropower scheme, after several years of contradictory reports there is still no final result.

7.6 Conclusion

In the last two decades a huge number of newly developed sites demonstrate that even under highly restrictive environmental conditions the peaceful and sustainable coexistence of small hydropower and the environment is possible. In SHP, it is much easier to meet environmental demands than in the field of big hydropower, where technical concerns are rather less flexible. Although the

exploitation of SHP is not in principle free of environmental problems, the wide range of effective mitigating measures offers many worthwhile approaches for the responsible, open-minded, and experienced designer. SHP and the protection of the environment are not a contradiction but an extraordinary interesting and exiting challenge.

¹ By Bernhard Pelikan (ÖVFK), Luigi Papetti (Studio Frosio) and Celso Penche (ESHA)

² European Commission - "Externalities of Energy - Volume 6 Wind and Hydro" EUR 16525 EN

³ S. Palmer. "Small scale hydro power developments in Sweden and its environmental consequences". HIDROENERGIA 95 Proceedings. Milano

⁴ F. Monaco, N. Frosio, A. Bramati, "Design and realisation aspects concerning the recovery of an energy head inside a middle European town" HIDROENERGIA 93, Munich

⁵ J. Gunther, H.P. Hagg, "Vollständig Überflutetes Wasserkraftwerk Karlstor/Heidelberg am Neckar", HIDROENERGIA 93, Munich

⁶ European Commission - "Externalities of Energy - Volume 6 Wind and Hydro" EUR 16525 EN.

⁷ Santos Coelho & Betamio de Almeida, "A computer assisted technique for the hydraulic design of fish ladders in S.H.P." HIDROENERGIA 95, Munich

⁸ J Osborne . New Concepts in Fish Ladder Design (Four Volumes), Bonneville Power Administration, Project 82-14, Portland, Oregon, 1985

⁹ Department of Energy, Washington, USA. "Development of a More Fish-Tolerant Turbine Runner" (D.O.E./ID.10571)

¹⁰ Dulas Ltd. Machynllyth, Powys, Wales SY20 8SX. e-mail dulas@gn.apc.org "Static screening systems for small hydro". HIDROENERGIA97 Conference Proceedings, page 190

¹¹ James J. Strong. "Innovative static self-cleaning intake screen protects both aquatic life and turbine equipment" HYDRO88 Conference papers.

¹² D.R. Lambert, A. Turpenny, J.R. Nedwell "The use of acoustic fish deflection systems at hydro stations", Hydropower & Dams Issue One 1997

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8. ECONOMIC ANALYSISⁱ

8.1. Introduction

An investment in a small hydropower scheme will incur costs as well as earn income over the life of the project. The costs include a fixed component - the capital cost, insurance, taxes other than the income taxes, rates etc. and a variable component operation and maintenance expenses, salaries, income tax etc.

At the end of the project, either limited by the authorisation period, or the condition of the asset the residual value will usually be positive, (although some administrative authorisations demand the abandonment of all the facilities that revert to the State).

The economic analysis is a comparison of costs and benefits that enables the investor/investors to make an informed choice whether to develop the project or abandon it. It is also possible that a choice may be made between different hydro projects so that the investment can be made in the one that gives the best return.

From an economic viewpoint, a hydropower plant differs from a conventional thermal plant, because its initial investment cost per kW is much higher but the operating costs are extremely low, since there is no need to pay for fuel.

The economic analysis can be made by either, including the effect of the inflation, or omitting it. Working in constant monetary value has the advantage of making the analysis independent of the inflation rate. Valued judgements are easier to make in this way. Because the analysis refers cash flows to the present time it is easy to judge the overall value of the investment.

If there are reasons to believe that certain factors will evolve at a different rate from inflation, these must be treated with differential inflation rate. For instance, if we assume that electricity tariffs will grow two percent less than inflation, while the remaining factors stay constant in value, the electricity price should show a decrease in the analysis by 2% every year.

8.2. Basic considerations

The estimation of the investment cost constitutes the first step of an economic evaluation. For a preliminary approach, the estimation can be based on the cost of similar schemes. IDAE (Instituto para la Diversificación y Ahorro de Energía, Spain) in its publication “Minicentrales Hidroeléctricas”ⁱⁱ analyses the cost of the different components of a scheme - weir, water intake, canal, penstock, powerhouse, turbines and generators, transformers and transmission lines. J. Fonkenelle also published monographs, but only for low-head schemesⁱⁱⁱ. The Departamento Nacional de Aguas e Energia Eléctrica (DNAEE) developed a computer program, FLASH, for small hydro feasibility studies^{iv}.

There are a number of software packages available to assist in the analysis of a potential site. PC based packages such as HydrA^v and Hydrosoft^{vi} are available on the Web and can often be downloaded. Some of them are limited to particular regions or countries whilst others are more generic. The RETScreen Pre-feasibility Analysis Software^{vii} is a generic, freely available software package with an on-line user manual. It enables users to prepare a preliminary evaluation of the

annual energy production, costs and financial viability of projects. Whilst identifying that the site has a technical potential is paramount, the key to any successful development is undertaking an economic analysis of a site that will provide an accurate indication of the investment cost required. During this analysis an essential consideration is the estimated cost per kW of the site.

In his communication to HIDROENERGIA'97 on the THERMIE programme, H. Pauwels from DG TREN, former DG XVII, he summarised data from schemes presented to the above programme and correlates the investment cost in €/kW installed for different power ranges and heads. Perhaps not surprisingly two characteristics become clear from this graph: costs increase as head decreases and similarly as scheme kW size decreases also. The conclusion being that small (less than 250kW), low head (less than 15m) schemes represent the highest relative costs for a scheme.



Figure 8-1 Specific cost of installed capacity

Also presented at HIDROENERGIA '97 from the computer program, Hydrosoft, was the set of curves in correlating the investment cost in €/kW and the installed capacity (between 100 kW and 10 MW) for low head schemes, with 2, 3, 4 and 5 m head.

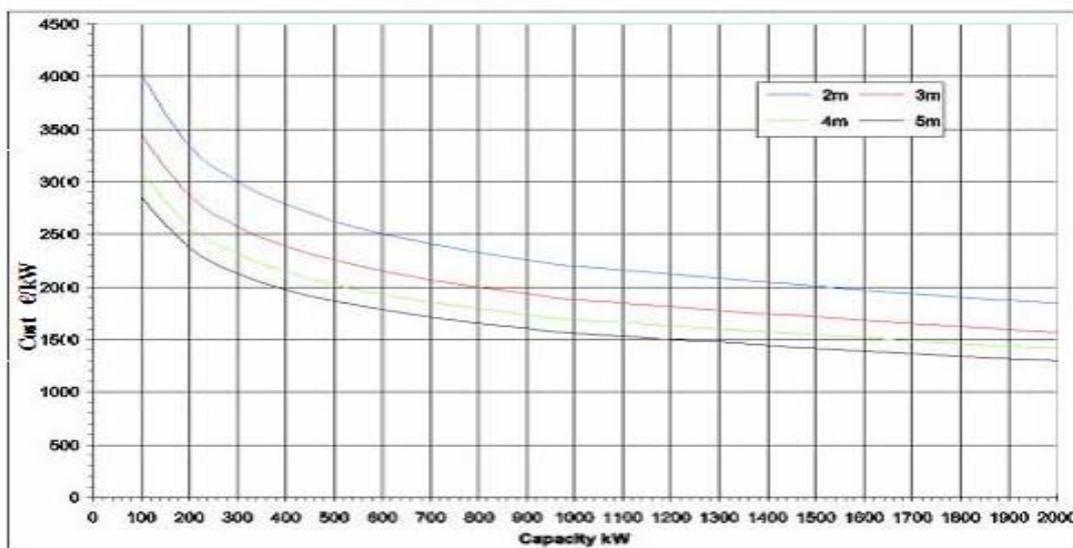


Figure 8-2 Investment costs for installed capacity for specific heads

More recent figures from ESTIR^{viii}, December 2002, show investment costs specific to small hydro and scheme kW size (but does not relate to head). These costs have quite a range and are shown in.

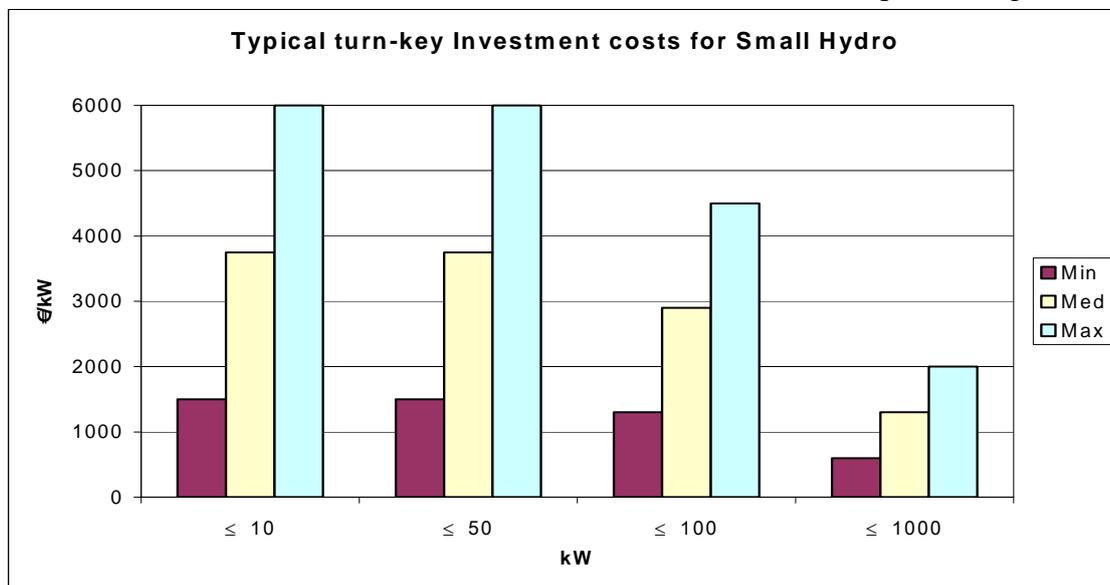


Figure 8-3 ESTIR turnkey investment costs for small hydro

These figures suggest that in the smaller kW range investment costs can be as high as 6000 €/kW in extreme cases. However, as a cost estimate is essential for economic analysis, it is also necessary to produce a preliminary design, including the principal components of the scheme. Based on this design, budget prices for the materials can be obtained from suppliers. Such prices cannot be considered as firm prices until specifications and delivery dates have been provided. This will come later, during the actual design and procurement process. Do not forget that in a plant connected to the grid, the costs for connection to the grid should be included, because according to various national regulations this line, although it often remains the property of the grid company, it is always built at the expense of the SHP developer. A plant close to the grid connection point will be always cheaper than one installed far from it. The same reasoning can be applied to telephone lines. In an unmanned plant, a telephone line to transmit telemetry and alarm signals is frequently used although, occasionally it might be cheaper to use the transmission line itself to establish a radio link. The use of the digital cellular telephone network is also increasingly used provided there is sufficient coverage.

8.3. Time value of Money

The ‘time value of money’ is the concept that a Euro received today is worth more than a Euro received at some point in the future, because the Euro received today can be invested to earn interest. Time value of money analysis generally involves the relationship between a certain amount of money, a certain period and a certain rate of compound interest. An investment project considers revenues and expenses that take place in very different time periods. In any economic analysis involving economic value there are always two variables, money and time. A certain amount of money paid or received at a point in time has a different value if it is paid or received at another point in time. Money can be invested during a certain period of time with the guarantee of a certain benefit. The term ‘present value’ stands for the current value of a future amount of money or a series

of payments, evaluated at a given interest rate. In order to determine the present value (PV) of a future amount of money or future value (FV), discounted at a given interest rate “r” (also called discounted rate), for a number of years “n”, the following formula is used:

$$PV_0 = \frac{FV_n}{(1+r)^n} = \frac{1}{(1+r)^n} FV_n$$

(8.1)

The term $1/(1+r)^n$ is called “present value factor” (PVF). Table 8.1 gives the value of this multiplier for different interest rates and time periods. Therefore, for a discounting rate r, the cost C_n (or the benefit B_n), disbursed or received in the year n, is discounted to the year zero by the equation:

$$C_0 = \left[\frac{1}{(1+r)^n} \right] C_n$$

(8.2)

The fraction within square brackets is ‘present value factor’. To find the comparable value of a given sum of money if it were received, or disbursed, at a different time, the above formula may be used or the corresponding PVF as given in left hand columns of Table 8.1 may be multiplied by the given sum. For instance, if the investor's opportunity earning potential were 8%, then €1500 received in 5 years from now, would be equivalent to a present value of:

$$\left[\frac{1}{(1+0.08)^5} \right] 1500 = \text{€ } 020.9$$

Cash flows occurring at different times can be converted to a common basis, using the discount method, either using the formulae, available on an electronic spreadsheet, or the Table 8.1. In Table 8.1, the discount factors are calculated from the discount formulas for various time periods and opportunity costs (expressed as rate of discount r). The time periods can be years, quarters, months etc. and the periodic discount rate will correspond to the period rate. If r is the annual discount rate then r/4 will be the discount rate corresponding to a quarter and 1/12r the corresponding rate for a month.

With the concept of present value for a future payment, investors can calculate the present value of the future sales price of a SHP plant. The formula is useful in understanding that an investment today has to be sold at a much higher price in the future if the investment is to be interesting from an economic point of view. Although the PVF could be used to solve any present value problem that would arise, it is convenient to define a second term in order to speed the arithmetic process: the present value of an annuity.

An annuity is a series of equal payments over a certain period of time. The present value of an annuity over n years, with an annual payment C (starting at the end of the first year) will be the result of multiplying C by a factor, a_n , equal to the sum of present value factors, PVF’s (v):-

$$a_n = v^1 + v^2 + v^3 \dots + v^n$$

It can be demonstrated that,

$$a_n = \frac{1 - v_n}{r} = \frac{(1+r)^n - 1}{r(1+r)^n} = \frac{1 - (1+r)^{-n}}{r} \tag{8.3}$$

Annuities are payments occurring regularly over a period of time “n”. With “C” being the annual payment and “PVA” the present value of the annuity, we can express the present value as the sum of future payments discounted at “r”:

$$PVA_n = C \left[\sum_{t=1}^n \frac{1}{(1+r)^t} \right] = C \frac{1 - \frac{1}{(1+r)^n}}{r} = C \frac{1 - (1+r)^{-n}}{r} = C * a_n \tag{8.4}$$

For instance the present value for a series of 200 Euro payments, over three years beginning at the end of the first year, will be given by the equation 8.4 and the PVF in the right hand columns of table 8.1. Assuming a discount rate of 8% then:-

$$PVA_3 = 200 \left[\sum_{t=1}^3 \frac{1}{(1+0.08)^t} \right] = 200 \frac{1 - \frac{1}{(1+0.08)^3}}{0.08} = 200 \frac{1 - (1+0.08)^{-3}}{0.08} = 200 * 2.5771 = 515.42€$$

The concept of present value of an annuity allows the evaluation of how much the annual sales revenue from the SHP plant electricity is worth to the investor. With electricity sales price of 4€cts/kWh and a yearly production of 100000 kWh, revenue per year (the annuity) is 4000€ What would be the value of this revenue stream over 10 years at present for a required return of 8% for the investor? Again, applying formula 8.4 and table 8.1 values:

$$PVA_{10} = 4000 \frac{1 - \frac{1}{(1+0.08)^{10}}}{0.08} = 4000 * 6.7101 = 26840.4€$$

Table 8-1 Present Value Factor (PVF) for various time periods’ n and opportunity cost r

n/r	Single payment				Uniform series of payments			
	6%	8%	10%	12%	6%	8%	10%	12%
1	0.9434	0.9259	0.9091	0.8929	0.9434	0.9259	0.9091	0.8929
2	0.8900	0.8573	0.8264	0.7972	1.8334	1.7833	1.7355	1.6901
3	0.8396	0.7938	0.7513	0.7118	2.6730	2.5771	2.4869	2.4018
4	0.7921	0.7350	0.6830	0.6355	3.4651	3.3121	3.1699	3.0373
5	0.7473	0.6806	0.6209	0.5674	4.2124	3.9927	3.7908	3.6048
6	0.7050	0.6302	0.5645	0.5066	4.9173	4.6229	4.3553	4.1114
7	0.6651	0.5835	0.5132	0.4523	5.5824	5.2064	4.8684	4.5638
8	0.6274	0.5403	0.4665	0.4039	6.2098	5.7466	5.3349	4.9676
9	0.5919	0.5002	0.4241	0.3606	6.8017	6.2469	5.7590	5.3282
10	0.5584	0.4632	0.3855	0.3220	7.3601	6.7101	6.1446	5.6502
11	0.5268	0.4289	0.3505	0.2875	7.8869	7.1390	6.4951	5.9377
12	0.4970	0.3971	0.3186	0.2567	8.3838	7.5361	6.8137	6.1944
13	0.4688	0.3677	0.2897	0.2292	8.8527	7.9038	7.1034	6.4235
14	0.4423	0.3405	0.2633	0.2046	9.2950	8.2442	7.3667	6.6282
15	0.4173	0.3152	0.2394	0.1827	9.7122	8.5595	7.6061	6.8109
16	0.3936	0.2919	0.2176	0.1631	10.1059	8.8514	7.8237	6.9740
17	0.3714	0.2703	0.1978	0.1456	10.4773	9.1216	8.0216	7.1196
18	0.3503	0.2502	0.1799	0.1300	10.8276	9.3719	8.2014	7.2497
19	0.3305	0.2317	0.1635	0.1161	11.1581	9.6036	8.3649	7.3658
20	0.3118	0.2145	0.1486	0.1037	11.4699	9.8181	8.5136	7.4694
21	0.2942	0.1987	0.1351	0.0926	11.7641	10.0168	8.6487	7.5620
22	0.2775	0.1839	0.1228	0.0826	12.0416	10.2007	8.7715	7.6446
23	0.2618	0.1703	0.1117	0.0738	12.3034	10.3711	8.8832	7.7184
24	0.2470	0.1577	0.1015	0.0659	12.5504	10.5288	8.9847	7.7843
25	0.2330	0.1460	0.0923	0.0588	12.7834	10.6748	9.0770	7.8431
26	0.2198	0.1352	0.0839	0.0525	13.0032	10.8100	9.1609	7.8957
27	0.2074	0.1252	0.0763	0.0469	13.2105	10.9352	9.2372	7.9426
28	0.1956	0.1159	0.0693	0.0419	13.4062	11.0511	9.3066	7.9844
29	0.1846	0.1073	0.0630	0.0374	13.5907	11.1584	9.3696	8.0218
30	0.1741	0.0994	0.0573	0.0334	13.7648	11.2578	9.4269	8.0552
31	0.1643	0.0920	0.0521	0.0298	13.9291	11.3498	9.4790	8.0850
32	0.1550	0.0852	0.0474	0.0266	14.0840	11.4350	9.5264	8.1116
33	0.1462	0.0789	0.0431	0.0238	14.2302	11.5139	9.5694	8.1354
34	0.1379	0.0730	0.0391	0.0212	14.3681	11.5869	9.6086	8.1566
35	0.1301	0.0676	0.0356	0.0189	14.4982	11.6546	9.6442	8.1755
36	0.1227	0.0626	0.0323	0.0169	14.6210	11.7172	9.6765	8.1924
37	0.1158	0.0580	0.0294	0.0151	14.7368	11.7752	9.7059	8.2075
38	0.1092	0.0537	0.0267	0.0135	14.8460	11.8289	9.7327	8.2210
39	0.1031	0.0497	0.0243	0.0120	14.9491	11.8786	9.7570	8.2330
40	0.0972	0.0460	0.0221	0.0107	15.0463	11.9246	9.7791	8.2438

8.4. Methods of economic evaluation

While the payback period method is the easiest to calculate most accountants would prefer to look at the net present value and the internal rate of return. These methods take into consideration the greatest number of factors, and in particular, they are designed to allow for the time value of money.

When comparing the investments of different projects the easiest method is to compare the ratio of the total investment to the power installed or the ratio of the total investment to the annual energy produced for each project. This criteria does not determine the profitability of a given scheme because the revenue is not taken into account and is really an initial evaluation.

8.4.1. Static methods

8.4.1.1. Payback method

The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The required number of years is termed the payback, recovery, or break-even period. The calculation is as follows:

$$\text{Payback period} = \frac{\text{investment cost}}{\text{net annual revenue}}$$

The method usually neglects the opportunity cost of capital. The opportunity cost of capital is the return that could be earned by using resources for an alternative investment rather than for the purpose at hand. Investment costs are usually defined as first costs (civil works, electrical and hydro mechanical equipment) and benefits are the resulting net yearly revenues expected from selling the electricity produced, after deducting the operation and maintenance costs, at constant value money. The payback ratio should not exceed 7 years if the small hydro project is to be considered profitable.

However, the payback does not compare the selection from different technical solutions for the same installation, or choosing among several projects that may be developed by the same promoter. In fact it does not consider cash flows beyond the payback period and thus does not measure the efficiency of the investment over its entire life.

Under the payback method of analysis, projects or purchases with shorter payback periods rank higher than those with longer paybacks do. The theory is that projects with shorter paybacks are more liquid, and thus represent less of a risk.

For the investor, when using this method it is advisable to accept projects that recover the investment and if there is a choice, select the project, which pays back earliest. This method is simple to use but it is attractive if liquidity is an issue but does not explicitly allow for the “time value of money” for investors.

8.4.1.2. Return on Investment method

The return on investment (ROI) calculates average annual benefits, net of yearly costs, such as depreciation, as a percentage of the original book value of the investment. The calculation is as follows:-

$$ROI = \frac{\text{net annual revenue} - \text{depreciation}}{\text{investment cost}} \times 100$$

For purposes of this formula, depreciation is calculated very simply, using the straight- line method:-

$$\text{Depreciation} = \frac{\text{cost} - \text{salvage value}}{\text{operational life}} e$$

Using ROI can give you a quick estimate of the project's net profits, and can provide a basis for comparing several different projects. Under this method of analysis, returns for the project's entire useful life are considered (unlike the payback period method, which considers only the period that it takes to recoup the original investment). However, the ROI method uses income data rather than

cash flow and it completely ignores the time value of money. To get around this problem, the net present value of the project, as well as its internal rate of return should be considered.

8.4.2. Dynamic methods

These methods of financial analysis take into account total costs and benefits over the life of the investment and the timing of cash flows.

8.4.2.1. Net Present Value (NPV) method

NPV is a method of ranking investment proposals. The net present value is equal to the present value of future returns, discounted at the marginal cost of capital, minus the present value of the cost of the investment. The difference between revenues and expenses, both discounted at a fixed, periodic interest rate, is the net present value (NPV) of the investment, and is summarised by the following steps:

1. Calculation of expected free cash flows (often per year) that result out of the investment
2. Subtract /discount for the cost of capital (an interest rate to adjust for time and risk) giving the Present Value
3. Subtract the initial investments giving the Net Present Value (NPV)

Therefore, net present value is an amount that expresses how much value an investment will result in, in today’s monetary terms. Measuring all cash flows over time back towards the present time does this. A project should only be considered if the NPV results in a positive amount.

The formula for calculating NPV, assuming that the cash flows occur at equal time intervals and that the first cash flows occur at the end of the first period, and subsequent cash flow occurs at the ends of subsequent periods, is as follows:

$$NPV = \sum_{i=1}^{i=n} \frac{R_i - (I_i + O_i + M_i)}{(1 + r)^i} + V_r$$

(8.5)

Where:

Where,

I_i = investment in period i

R_i = revenues in period i

O_i = operating costs in period i

M_i = maintenance costs in period i

V_r = residual value of the investment over its lifetime, where equipment lifetime exceeds the plant working life

r = periodic discount rate, where the period is a quarter, the periodic rate is $\frac{1}{4}$ of the annual rate

n = number of lifetime periods e.g. years, quarters, months etc.

The calculation is usually done for a period of thirty years, because due to the discounting techniques used in this method both revenues and expenses become negligible after a larger number of years.

Different projects may be classified in order of decreasing NPV. Projects where NPV is negative will be rejected, since that means their discounted benefits during the lifetime of the project are insufficient to cover the initial costs. Among projects with positive NPV, the best ones will be those with greater NPV value.

The NPV results are quite sensitive to the discount rate, and failure to select the appropriate rate may alter or even reverse the efficiency ranking of projects. Since changing the discount rate can affect the outcome of the evaluation, the rate used should be chosen carefully. For a private developer, the discount rate will be such that allows him to choose between investing in a small hydro project or in keeping his saving in the bank. This discount rate, depending on the inflation rate, usually varies between 5% and 12%.

If the net revenues are constant in time (uniform series), their discounted value is given by the equation (8.3).

The method does not distinguish between projects with high investment costs promising a certain profit, from another that produces the same profit but needs a lower investment, as both have the same NPV. Hence a project requiring €1 000 000 in present value and promises €100 000 profit shows the same NPV as another one with a €100 000 investment and promises €200 000 profit (both in present value). Both projects will show a €100 000 NPV, but the first one requires an investment ten times higher than the second does.

There has been some debate^{ix} regarding the use of a constant discount rate when calculating the NPV. Recent economic theory suggests the use of a declining discount rate is more appropriate for longer-term projects – those with a life-span over thirty years and in particular infrastructure projects. Examples of these could be climate change prevention, construction of power plant and the investment in long-term infrastructure such as roads and railways. Taking Climate Change as an illustrative example, mitigation costs are incurred now with the benefits of reduced emissions only becoming apparent in the distant future. When using a constant discount rate these benefits are discounted to virtually zero providing little incentive, however the declining discount rate places a greater emphasis on the future benefits.

Correct use of a declining discount rate places greater emphasis on costs and benefits in the distant future. Investment opportunities with a stream of benefits accruing over a long project lifetime therefore appear more attractive.

8.4.2.2. Benefit-Cost ratio

The benefit-cost method compares the present value of the plant benefits and investment on a ratio basis. It compares the revenue flows with the expenses flow. Projects with a ratio of less than 1 are generally discarded. Mathematically the $R_{b/c}$ is as follows:-

$$RB/C = \left[\sum_0^n \frac{R_n}{(1+r)^n} \right] / \left[\sum_0^n \frac{(I_n + M_n + O_n)}{(1+r)^n} \right] \tag{8.6}$$

where the parameters are the same as stated in (8.5)

8.4.2.3. Internal Rate of Return method

The internal rate of return (IRR) method of analysing a project allows the consideration of the time value of money. Basically, it determines the interest rate that is equivalent to the Euro returns expected from the project. Once the rate is known, it can be compared to the rates that could be earned by investing the money in other projects or investments. If the internal rate of return is less than the cost of borrowing used to fund your project, the project will clearly be a money-loser. However, usually a developer will insist that in order to be acceptable, a project must be expected to earn an IRR that is at least several percentage points *higher* than the cost of borrowing. This is to compensate for the risk, time and problems associated with the project.

The criteria, for selection between different alternatives is, usually, to choose the investment with the highest rate of return.

To find the IRR a process of trial and error is used, whereby the net cash flow is computed for various discount rates until its value is reduced to zero. Electronic spreadsheets use a series of approximations to calculate the internal rate of return. The following examples illustrate how to apply the above-mentioned methods to a hypothetical small hydropower scheme:

8.4.3. Examples

8.4.3.1. Example A

Installed capacity: 4 929 kW

Estimated annual output 15 750 MWh

First year annual revenue €1 005 320

It is assumed that the price of the electricity will increase every year one point less than the inflation rate.

The estimated cost of the project in € is as follows:

1. Feasibility study 6 100
2. Project design and management 151 975
4. Civil works 2 884 500
3. Electromechanical equipment 2 686 930
5. Installation 686 930

Sub-Total 6 416 435

Unforeseen expenses (3%) 192 493

Total investment €6 608 928

The investment cost per installed kW would be:

$6\,608\,928 / 4\,929 = 1\,341 \text{ €/kW}$

The investment cost per annual MWh produced is: 420 €/MWh

The operation and maintenance cost per year, estimated at 4% of the total investment, is: €264 357.

In the analysis, it is assumed that the project will be developed in four years. The first year will be devoted to the feasibility study and to the planning and consents process. Hence, at the end of first year, both the entire feasibility study cost and half the cost of project design and management will be spent. At the end of second year the other half of the design and project management costs will be spent. At the end of the third year 60% of the civil works will be finished and 50% of the electromechanical equipment paid for. At the end of the fourth year the whole development is finished and paid. The scheme is commissioned at the end of the fourth year and becomes operative at the beginning of the fifth (year zero). The electricity revenues and the O&M costs are made effective at the end of each year. The electricity prices increases by one point less than the inflation rate. The abstraction license duration has been fixed at 35 years, starting from the beginning of the second year (year -2). The discount rate is 8% and the residual value nil. Table .2 shows the cash flows along the project lifetime.

Table 8-2 Cash flow analysis

Investment cost - €	O&M costs - €	Discount rate - r	Lifetime - n
6 608 928	264 357	8%	35 yr.

Year	Investment	Revenues	O&M	Cash Flow	Cumulated Cash Flow
-4	82 087			- 82 087	- 82 087
-3	75 988			- 75 988	- 158 075
-2	3 074 165			-3 074 165	-3 232 240
-1	3 376 688			-3 376 688	-6 608 928
0		1 005 320	264 357	740 963	-5 867 965
1		995 267	264 357	730 910	-5 137 055
2		985 314	264 357	720 957	-4 416 098
3		975 461	264 357	711 104	-3 704 995
4		965 706	264 357	701 349	-3 003 645
5		956 049	264 357	691 692	-2 311 953
6		946 489	264 357	682 132	-1 629 821
7		937 024	264 357	672 667	- 957 155
8		927 654	264 357	663 297	- 293 858
9		918 377	264 357	654 020	360 162
10		909 193	264 357	644 836	1 004 998
11		900 101	264 357	635 744	1 640 743
12		891 100	264 357	626 743	2 267 486
13		882 189	264 357	617 832	2 885 318
14		873 368	264 357	609 010	3 494 329
15		864 634	264 357	600 277	4 094 605
16		855 988	264 357	591 630	4 686 236
17		847 428	264 357	583 071	5 269 306
18		838 953	264 357	574 596	5 843 903
19		830 564	264 357	566 207	6 410 109
20		822 258	264 357	557 901	6 968 010
21		814 036	264 357	549 679	7 517 689
22		805 895	264 357	541 538	8 059 227
23		797 836	264 357	533 479	8 592 706
24		789 858	264 357	525 501	9 118 207
25		781 959	264 357	517 602	9 635 809
26		774 140	264 357	509 783	10 145 592
27		766 398	264 357	502 041	10 647 633
28		758 734	264 357	494 377	11 142 011
29		751 147	264 357	486 790	11 628 800
30		743 636	264 357	479 278	12 108 079
31		736 199	264 357	471 842	12 579 921
32		728 837	264 357	464 480	13 044 401

Net Present Value (NPV)

Equation (8.5) can be written as follows:

$$NPV = \sum_{t=4}^{36} \frac{R_t - (O_t + M_t)}{(1 + r)^t} - \sum_{t=0}^3 \frac{I_t}{(1 + r)^t}$$

To calculate the above equation it should be taken into account that R_t varies every year because of change in electricity price. Calculating the equation manually or using the NPV value from an electronic spreadsheet, the NPV obtained is: **€444 803**

Internal Rate of Return (IRR)

The IRR is computed using an iterative calculation process, using different discount rates to get the one that makes NPV = 0, or using the function IRR in an electronic spreadsheet.

NPV using r = 8% NPV = €444 803

NPV using r = 9% NPV = -€40 527

Following the iteration and computing NPV, when the discount rate r=8.91% then the NPV is zero and consequently IRR = 8.91%

Ratio Benefit/cost

The NPV at year 35 of the revenues is €8 365 208 and the NPV at year 35 of the costs is €7 884 820. This gives:-

$$R_{b/c} = 1.061$$

Varying the assumptions can be used to check the sensitivity of the parameters. Table 3 and Table 4 illustrate respectively the NPV and R_{b/c}, corresponding to the example A, for several life times and several discount rates.

Table 8-3 NPV against discount rate and lifetime

Yr./r	6%	8%	10%	12%
25	1 035 189	21 989	- 668 363	-1 137 858
30	1 488 187	281 347	- 518 242	-1 050 050
35	1 801 647	444 803	- 431 924	-1 003 909

Table 8-4:R_{b/c} against discount rate and lifetime

Yr./r	6%	8%	10%	12%
25	1.153	1.020	0.906	0.811
30	1.193	1.050	0.930	0.830
35	1.215	1.061	0.933	0.828

The financial results are very dependent on the price paid for the electricity. Table 8.5 gives the values NPV, R_{b/c} and IRR for different tariffs – 35% and 25% lower and 15% and 25% higher than that assumed in example A

Table 8-5 NPV, R_{b/c} and IRR for different tariffs (were r is 8% and the period is 35 years)

	65%	75%	100%	115%	125%
NPV	-2 266 144	-1 491 587	444 803	1 606 638	2 381 194
B/C	0.690	0.796	1.061	1.220	1.326
IRR	2.67%	4.68%	8.91%	11.16%	12.60%

8.4.3.2. Example B

Shows the annual cash flows if the investment is externally financed with the following assumptions:-

- 8% discount rate
- Development time 4 years
- Payments and expenses at the end of the year
- Approximately 70% of the investment financed by the bank with two years grace
- Finance period 12 year
- Bank interest rate 10%
- Project lifetime 30 years

The disbursements are identical as in example A. The bank in the first two years collects only the interest on the unpaid debt, see Table 6.

It must be remarked that the example refers to a hypothetical scheme, although costs and revenues are reasonable in Southern Europe. The objective is to illustrate a practical case to be followed and later applied to another scheme with different costs and revenues.

Table 8-6 Example B – Annual cash flows for externally financed investment

Investment cost - €	O&M costs - €	Discount rate	Lifetime - t	Bank loan	Loan term - yr.	Interest on loan	NPV	R _{b/c}	IRR
6 608 928	264 357	8%	35 yr.	4 515 599	12	10%	208 208	1.061	8.72%

Yr	Investment	Bank loan	Investor's investment	Principal repayment	Principal residual	Interest on loan	Revenues	O&M	Investor Cash Flow	Cumulated Cash Flow
-4	- 82 087								- 82 087	- 82 087
-3	- 75 988								- 75 988	- 158 075
-2	-3 074 165	-2 151 916	- 922 249	0	-2 151 916				- 922 249	-1 080 324
-1	-3 376 688	-2 363 683	-1 013 005	0	-4 515 599	- 215 192			-1 013 005	-2 093 329
0				0	-4 515 599	- 451 560	1 005 320	- 264 357	289 403	-1 803 926
1				- 135 023	-4 380 576	- 451 560	995 267	- 264 357	144 327	-1 659 599
2				- 296 835	-4 083 741	- 438 058	985 314	- 264 357	- 13 936	-1 673 535
3				- 326 519	-3 757 222	- 408 374	975 461	- 264 357	- 23 789	-1 697 324
4				- 359 171	-3 398 051	- 375 722	965 706	- 264 357	- 33 544	-1 730 868
5				- 395 088	-3 002 963	- 339 805	956 049	- 264 357	- 43 201	-1 774 069
6				- 434 596	-2 568 367	- 300 296	946 489	- 264 357	- 52 761	-1 826 829
7				- 478 056	-2 090 311	- 256 837	937 024	- 264 357	- 62 226	-1 889 055
8				- 525 862	-1 564 449	- 209 031	927 654	- 264 357	- 71 597	-1 960 652
9				- 578 448	- 986 001	- 156 445	918 377	- 264 357	- 80 873	-2 041 525
10				- 636 293	- 349 708	- 98 600	909 193	- 264 357	- 90 057	-2 131 582
11				- 349 708	0	- 34 971	900 101	- 264 357	251 066	-1 880 516
12							891 100	- 264 357	626 743	-1 253 773
13							882 189	- 264 357	617 832	- 635 940
14							873 368	- 264 357	609 010	- 26 930
15							864 634	- 264 357	600 277	573 347
16							855 988	- 264 357	591 630	1 164 977
17							847 428	- 264 357	583 071	1 748 048
18							838 953	- 264 357	574 596	2 322 644
19							830 564	- 264 357	566 207	2 888 851
20							822 258	- 264 357	557 901	3 446 752
21							814 036	- 264 357	549 679	3 996 430
22							805 895	- 264 357	541 538	4 537 968
23							797 836	- 264 357	533 479	5 071 448
24							789 858	- 264 357	525 501	5 596 948
25							781 959	- 264 357	517 602	6 114 551
26							774 140	- 264 357	509 783	6 624 333
27							766 398	- 264 357	502 041	7 126 375
28							758 734	- 264 357	494 377	7 620 752
29							751 147	- 264 357	486 790	8 107 542
30							743 636	- 264 357	479 278	8 586 820
31							736 199	- 264 357	471 842	9 058 662
32							728 837	- 264 357	464 480	9 523 142

8.4.3.3. Financial analysis of built schemes in Europe

In Table 8.7 several European schemes have been analysed. It must be noted that both investment costs and buy-back tariffs correspond to the year 1991, and do not necessarily reflect the situation today.

Table 8.7: Financial analysis of real schemes in Europe

Country		Germany	France	Ireland	Portugal	Spain
Rated discharge	m ³ /s	0.3	0.6	15	2	104
Gross head	m	47	400	3.5	117	5
Type of Turbine		Francis	Pelton	Kaplan	Francis	Kaplan
Installed capacity	kW	110	1900	430	1630	5000
Investment cost	€	486 500	1297 400	541 400	1148 000	5578 928
Working hours		8 209	4 105	8 400	4 012	3 150
Annual production	MWh	903	7800	3612	6540	15750
Tariff	€/MWh	76.13	53.65	23.23	53.54	63.82
Revenue	€/Yr	68 745	418 443	83 907	350 128	1005 165
O&M	€/Yr	19 850	51 984	25 176	22 960	157 751
O&M	%	4.08	4.01	4.65	2.00	2.83
Gross Profit	€/Yr	48 895	366 459	58 731	327 168	847 414

Economic Analysis						
Capital cost	€/kW	4 423	683	1 259	704	1 116
Capital cost	€/MWh	539	166	150	176	354
Simple payback period	Yr.	9.95	3.54	9.22	3.51	6.58
NPV	€	63 374	2 649 850	115 910	2 375 270	3 739 862
IRR	%	9.37	28.23	10.33	28.49	14.99
B/C		1.15	2.72	1.16	2.82	1.64

The figures have been calculated using a discount rate of 8% over a lifetime of 30 years. You can see that ratios of investment per kW installed, or by annual MWh, produced differ considerably from scheme to scheme. Actual civil works, electromechanical equipment costs varies from country to country. Environmental requirements - affecting investment costs- differ not only from country to country but also from region to region. Buy-back electricity tariffs can be five times higher in one country than in another.

8.5. Tariffs and Incentives

A developer's economic analysis of a scheme would be simplified if electricity tariffs for a MWh were a known and stable entity. However, this is not the case and the markets vary constantly – the present move to liberalise and open up the markets to competition and the promotion of RE's serves as a good example. Tariffs are agreed in different ways between the generator and supplier and are influenced by national policy. These policies can and do vary from country to country and are reviewed and altered frequently making it difficult to provide more than an overview. Tariffs negotiated through some form of power purchase agreement with the supplier will vary from country to country and will be strongly influenced by that country's national policy. It is therefore important for the developer to understand clearly the implications of the national policy. Similarly, the developer should investigate what supplementary measures are available for the promotion of new RE developments. Chapter 9 (Appendix) provides the different categories of tariff structures and support schemes available in the EU-15. Table 8.8 shows the current prices agreed within the different support schemes in force in the year 2003 in the EU.

Member State	Price for sale to the grid (€/cents/kWh)
Belgium	Wallonia: 12.3 = 3.3 (market price) + 9 (green certificate)

	Flanders: 12.8 = 3.3 (market price) + 9.5 (green certificate)
Denmark	8.48
Germany	7.67 (< 500 kW) 6.65 (500 kW - 5 MW)
Greece	<i>Interconnected system: 6.29 + 113/month</i> <i>Non-interconnected islands: 7.78</i>
Spain	6.49 = 3.54 (pool price) + 2.95 (premium)
France	Operating before 2001: 7.32 + bonus for regularity of 0.75 (winter) and 2.94 (summer) Commissioned after 2001: <i>SHP < 500 kW: 8.55 + regulatory premium up to 1.52 (winter) and 4.52 (summer)</i> <i>SHP > 500 kW: 7.69 + + regulatory premium up to 1.52 (winter) and 4.07 (summer)</i>
Ireland	6.41 (weighted average price)
Italy	4.6 (spot electricity price) + 10.0 (green certificates)
Luxembourg	3.1 (electricity price) + 2.5 (premium only for plants under 3 MW)
Netherlands	3.3 (market price) + 6.8 (premium)
Austria	<u>Old plants</u> 1 st GWh: 5.68 1 – 4 GWh: 4.36 4- 14 GWh: 3.63 14-24 GWh: 3.28 + 24 GWh: 3.15 <u>New plants</u> <i>Rebuilt plants with a production increase per year > 15%</i> 1 st GWh: 5.96 1 – 4 GWh: 4.58 4- 14 GWh: 3.81 14-24 GWh: 3.44 + 24 GWh: 3.31 <i>New plants or Rebuilt plants with a production increase per year > 50%</i> 1 st GWh: 6.25 1 – 4 GWh: 5.01 4- 14 GWh: 4.17 14-24 GWh: 3.94 + 24 GWh: 3.78
Portugal	7.2
Finland	2.6 (market price) + 0.42 premium if < 1 MW + subsidy covering 30% of the investment cost
Sweden	4.9 = 2.3 (certificate level) + 2.6 (Nordpool price)
United Kingdom	2 (Average price for electricity in the energy market) + 0.38 (exemption to the Climate Change Levy) 4.2 (value of ROC's). When an electrical supply company provide renewable energy to 10% of its costumers it gets the 4.2 but if it fails to provide that percentage it has to pay 4.2 to the government.

ⁱ By Jamie O’Nians (IT Power), Gema San Bruno (ESHA), Maria Laguna (ESHA), Celso Penche (ESHA) and the special contribution from Katharina Krell (EUREC Agency)

ⁱⁱ IDAE. Manual de Minicentrales Hidroeléctricas. Edición Especial CINCO DIAD. 1997

ⁱⁱⁱ J. Fonkenelle. Comment sélectionner une turbine pour basse chute. Proceedings HIDROENERGIA 91 ,AGENCE FRANCAISE POUR LA MAITRISE DE L'ENERGIE

^{iv} DNAEE "APROVEITAMENTOS HIDRELETRICOS DE PEQUENO PORTE" Volumen V "Avaliação de Custos e Benefícios de Pequenas Centrais Hidrelétricas" Modelo FLASH, Brasília 1987

^v HydrA - PC-based software package for rapidly estimating hydropower potential at any location in the UK or Spain. The software, currently available for Spain and the UK, is being developed for other countries in the European Union. (Institute of Hydrology, UK, 2000, <http://www.nerc-wallingford.ac.uk/ih/H>)

^{vi} P. Fraenkel et al "Hydrosoft: A software tool for the evaluation of low-head hydropower Resources". HIDROENERGIA97 Conference Proceedings, page 380

^{vii} Natural Resources, Canada: Canmet, Energy Diversification Research Lab The RETScreen Analysis Software is available as a free download at www.retscreenc.gc.ca. Or by mail from CANMET Energy Diversification Research Lab., 1615 Lionel-Boulet PO Box 4800, Varennes PQ, Canada J3X 1S6

^{viii} Scientific and Technological References Energy Technology Indicators

<http://www.cordis.lu/eesd/src/indicators.htm>

^{ix} Hepburn C, (2002) Long-Run Discounting, Utilities Journal 42, September

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9 ADMINISTRATIVE PROCEDURES¹

9.1 Introduction

One major barrier to the further development of electricity from renewable energy sources are the administrative and planning procedures that potential generators must respect, which is particularly a problem for small and medium-sized companies (SMEs) that make up a significant proportion of companies in this sector.

According to the EU Directive 2001/77/EC (RES-E Directive), Member States of the European Union are required to review their existing legislative and regulatory frameworks concerning authorisation procedures in order to reduce regulatory and non-regulatory obstacles, to rationalise and speed up administrative procedures and to ensure that the rules are transparent and non-discriminatory. These rules have to take account of the particular characteristics of the different technologies using renewable energy sources. The Directive also mentions the obligation of the Member States to report to the European Commission on this review procedure by defining an action to be taken to reduce obstacles in this area. This report has to give an overview of progress made in:

- The co-ordination between the different administrative bodies involved concerning time limits, reception and handling of authorisation requests;
- The establishment of possible guidelines for activities connected with targets, so as to improve administrative procedures and the feasibility of speedy planning for the RES-E producers;
- The appointment of an authority to act as a mediator in disputes between the authorities responsible for issuing authorisations and requesters.

In the Commission's final report on the implementation of the RES- E Directive and on the basis of the Member States' reports, the Commission will evaluate the best practices for reducing regulatory and non-regulatory barriers to increasing RES-E production.

So far administrative procedures vary among Member States, best practices have not yet been defined and part of the procedures, which are now used should be modified in the coming years.

Nevertheless and in order to give to the new SHP developer some information on the administrative process that are needed to implement and to run a SHP plant, this chapter summarises the various types of general procedures and it illustrates some Member States' examples.

9.2 Types of procedures²

The implementation of a SHP plant can be looked at from various points of view:

- Energy generation
- Impact on water quality, flora and fauna of the river, and all environmental aspects
- Construction requirements
- Connection to the grid
- Landed properties
- etc...

Regulations have to take into account these various aspects, which are under the responsibility of different authorities. These authorities and responsibilities are different in each Member State depending on the political and administrative organization and on its involvement in the development of renewable energy sources.

In this context, the procedures vary from one country to another, but also within a country from one region to the other and even often, in the same region, from one project to the other. These procedures - that are far from being transparent, objective and non discriminatory- are supervised by several local administrations, very sensitive to pressure groups, which multiply the number of interlocutors, and extend the time to take decisions (up to 58 permits from different administrations are necessary in some Italian locations). In all countries the project has to be made public and people can react.

9.2.1 Energy regulation – Water rights

The water of a river is used for different purposes: irrigation, fishing, industrial use, leisure, etc...Regulations are necessary in order to allow the best possible access to these various uses. In almost all Member States water has public domain status (in Ireland and in some Nordic countries, water rights are regulated according to the riparian rights system).

Regulation of the use of the energetic aspects has been developed during the 20th century with the development of electricity. For example, Article 1 of the French law of 16 October 1919 specifies “no one can use the energy of tides, lakes and water courses without a concession or an authorization from the State”. It specifies that “small” plants (< 4 500 kW, since 1980) can be run by private producers with an authorization, and that bigger plants are to be run under a concession procedure.

The procedure is lengthy, because the river authority, generally responsible for it, should exchange information with the regional administration that is responsible for the environmental aspects. In some countries it can take more than five years to agree it. Once the plant is built, the competent authorities should verify on the site that the works conform to the requirements of the water use licence and then the minutes of the visit may constitute the permission to operate the plant.

Table 9.1 shows the authority granting rights for water use and the validity time of the authorization in the European Union, according to information collected in 1997³.

Table 9.1: Rights for water use in the EU-15

Country	Authority granting rights for water use	Validity time of the authorization
Belgium	< 1MW the provinces	Undetermined
	> 1MW same + Ministry of Energy	33 a 99 years
Denmark	Ministry of Energy	Undetermined
Germany	Länders	30 years
Greece	Ministry of Energy	10 years, renewable
Spain	Basin authority except in some rivers in Catalunya and Galicia	25 years + 15 of grace
France	< 4,5 MW Department Prefecture	In practice up to 40 years
	> 4,5 MW State	
Ireland	Not needed. Riparian rights in force	Perpetual
Italy	< 3MW regional authorities	30 year
	> 3MW Ministry of Industry	
Luxemburg	Ministries of Agriculture, Public Works, Environm. & Employment + local authorities	Undetermined
Netherlands	National & Local Water Boards	At minimum 20 years
Austria	< 200 kW local governments	Usual 30 years
	> 200 kW country governments	Possible more (60-90 years)
Portugal	DRARN (Regional Authority for Environment & Natural Resources)	35 years renewable
Sweden	Water Court	Perpetual (30 years)
U. K	Environmental Agency	England & Wales 15 years
	In Scotland not required if P<1MW;	Scotland undetermined
	If P>1 MW Secretary of State	

9.2.2 Environmental procedures

Since the 1970's environmental integration has become a relevant element of SHP projects and therefore most of the legislation in force in the European Member States includes the protection of the Environment.

At European level, there are currently two pieces of legislation with an impact in SHP projects:

- Natura 2000
- Directive 2000/60/CE (Water Framework Directive).

9.2.2.1 Environmental Impact Assessment

In most of the Member States, an environmental impact assessment (EIA) must be carried out in order to get the licence for water use.

This study is a scientific and technical analysis, which makes an inventory of the present situation and foresees the consequences on the environment to be expected from the implementation of the project. It concerns the fauna and the flora, the sites and landscapes, the ground, the water, the air, the climate, the natural surroundings and the biological equilibriums, the protection of goods and of the cultural patrimony, the comfort of the neighbourhood (noise, vibrations, smells, lightning), hygiene, security, public salubrity and health.

It is a synthesis of various environmental expertises implemented on the site: hydro-biological expertises, choice of the reserved flow, landscape analysis, etc...

An EIA has three main purposes:

- *Protection of the environment.* It does not only cover the conservation of spaces and species and the classification of territories in order to take them away from the human activities, but also it integrates the environment in planning actions. Therefore, it means to conceive projects (i) respecting man, landscape and natural mediums, (ii) which spare space and natural resources and (iii) limit water, air and ground pollution.
- *Information for the public authorities and the public.* As a tool for the information of the public authorities, the EIA is an official piece of the administrative decision file. It is also a tool for the information of the public, in particular in the public inquiries.
- *Help for decision.* As a scientific and technical analysis of the environmental constraints, the EIA constitutes one of the preliminary studies the developer has to implement. Together with the technical and economic studies, it contributes in improving the project.

9.2.2.1 Reserved flow

The flow of water giving a satisfactory generation of electricity while preserving the aquatic habitat, various environmental parameters whilst maintaining the various uses of the river, has been traditionally the main object of discussion between investors on the one hand and fishermen, environmental agencies and associations for the preservation of the environment on the other hand. Whereas for the developer producing electricity without damaging the global atmosphere merits every kind of support without heavy curtailments in the generation capacity² for the environmental

agencies and various associations concerned by the preservation of the environment, a low reserved flow is equivalent to an attack on the public good: the aquatic fauna.

The rules have generally been established at national level and only fixed at a minimum value. This has allowed local authorities to set at least the minimum and in many cases impose reserved flow values at an unreasonably high value. Following the approval by the Council of the Water Directive (Directive 2000/60/EC of 23 October 2000) water authorities are becoming more involved in this definition. Whereas in the past the national laws determined the reserved flow as a certain percentile of the module (inter annual average flow), the water authorities study the different stream reaches including hydrological and wildlife data collection, water quality and aquatics 1D/2D models. The values found for the reserved flow are usually higher but are at least scientifically determined.

The developer has to present in his EIA the value he proposes and the way it is calculated.

But, as detailed in chapter 7, the formulas are many and their number tends to increase day by day. This is a real problem for the legislator who has to set up the regulation, and in concrete cases it makes it difficult to have reference values or formulas to comply with. The main types of methods are detailed in chapter 7⁴:

- Methods based on hydrologic or statistic values
- Formulas based on velocity and depth of water
- Methods based on multi-objective planning taking into consideration ecological parameters.

Inside a given group of methods, the differences in the results can be very significant from one method to another.

No global comparison is possible between different groups of methods, as they do not refer to the same data. It is only possible to compare the results of different types of methods in real cases on which one knows all the necessary data. The application of 24 different methods to a wide low slope river gave 24 different results and the ratio between maximum and minimum value of the reserved flow was 192! Even when the four highest and the four lowest results are not considered then the ratio was still 14 between the highest and lowest results.

A consequence of all these different methods is that the national regulations can also be very different.

In the following paragraphs a very brief survey will be made in order to give an idea about the different methods applied.

Germany

There is no regulation valid for the whole country. The *Länder* have their specific regulation. A very common approach depends on the “mean minimum flow” (MNQ). Usually 1/3 to 1/6 is the amount of residual flow. More often the 1/3 option is chosen. The governmental representatives take the final decision during the granting procedure.

Greece

Reserved flow must be at least 1/3 of the average summer flow rate of the river.

Spain

In the 1985 Spanish Water Act the residual flow was established at 10% of the inter-annual average flow. This was considered by the different autonomic and local institutions as a minimum value, and in every new project a higher and often arbitrary value has been fixed. In the new Water Act of July 2001 the reserved flow must be established in the "River basin management plans" to be made by the corresponding river authorities (in Spain there are 14). In fact, up to now, only one river authority (the Basque) has elaborated a computer programme to fix it.

France

The minimal flow should not be lower than 1/10 of the module of the river corresponding to the inter-annual medium flow, evaluated from information available relating to a five years minimum period, or the flow with the immediately upstream of the work, if this one is lower. However, for the rivers or parts of rivers whose module is higher than 80 m³/s, a decree of Council of State can, for each one of them, fix a lower flow, which should not be below 1/20 of the module.

Italy

The reserved flow rules are fixed by River Basin Authorities or by Regional Governments and there are many regulations to conform to. Anyway the general tendency is for hypsographic methods with correction factors. The regulation is currently under review.

Austria

Austria has no general formula to be applied but some approaches to obtain a "correct" value. Usually the decision is taken by an official expert, including the granting procedure and this can lead to variability as the expertise of different people leads to different results. A first approximation is usually done with hydrological parameters, using the range between "annual mean minimum flow" (MNQ) and "annual minimum flow" (NNQ). A useful but sometimes expensive tool to avoid a rather high fixation is the presentation of a specific expertise based on dotation testing. Governmental experts will in most cases accept the result.

Portugal

Reserved flow must be equal or higher than 1/10 of the average inter-annual flow rate.

United Kingdom

The UK has no standard method. The main river authority (Environment Agency) looks at each site on an individual basis before granting a license. The starting point for negotiations is usually Q95 (that is the discharge which flows for more than 95% of the year), but it can be more or less than this in reality.

In Scotland, reserved flow must be equal or higher than 45% of the average inter-annual flow rate.

Lithuania

The Lithuanian territory is split up into two different hydrological regions in which different reserved flow values are imposed. For the first hydrological region, where the rivers have irregular

flow pattern; reserved flow is equivalent to the low flow warm season (from April to October) of 30 days duration value corresponding to the 5-years return period (probability - 0.80). The second hydrological region, which characterized by more regular river flow pattern, the reserved flow value is less and it is calculated using above methodology, but low flow return period is fixed at 20-years (probability - 0.95). In the diversion schemes, independently of the type of hydrological region, the minimum reserved flow in channel for diverted water is fixed at 10% of the long-term average seasonal flow.

Switzerland

Although Switzerland is not part of the EU their regulations concerning reserved flow are worth mentioning. The fixation is based upon the Q_{347} , (discharge appearing more than 95% of the year), obviously a kind of low flow. The graph shows the dependencies:

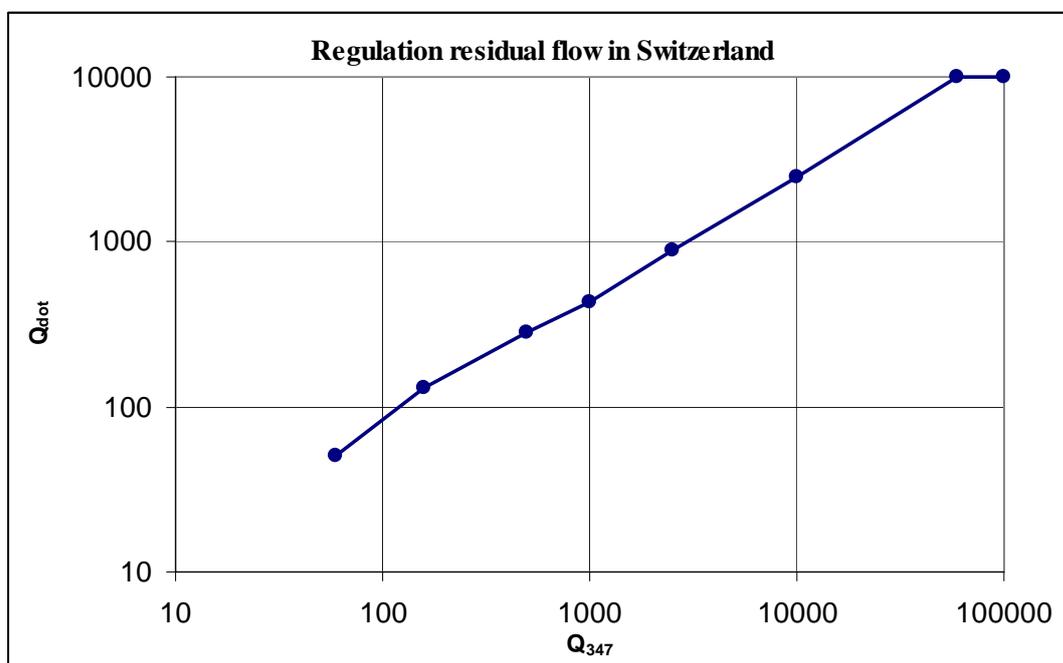


Figure 9.1: Regulation of the reserved flow in Switzerland

At very little discharge the reserved flow starts with 80% of Q_{347} , at 10 000l/s the percentage has been reduced to 25%, and from 60 000 l/s it stays at 10 000 l/s.

9.2.3 Public Inquiry

In some Member States, the developer has to submit the project to a public inquiry, this procedure being generally simplified for small capacity plants. This inquiry is demanded by the authority in charge of the decision of approving the implementation of the plant. The objective of this inquiry is to inform the public and to collect its opinions, suggestions and counter-proposals so that the public has been included and the authority has at its disposal all the necessary information.

An auditor leads the inquiry: site visit, demand for complementary information, management of a public meeting, and extension of the inquiry time. Its mission is concluded by a report to the competent authority taking into account the observations of the public. The auditor must write consistent and clear conclusions and specify whether he agrees with the project or not, or if he

would agree with reserves or conditions. The authority can take the conclusions of the auditor report into account or not.

9.2.4 Construction requirements

A building licence is generally necessary too. It is delivered separately from the water right. It is the responsibility of the town-planning authorities and its procedure is defined within the town-planning rules of the country or of the region. It often includes a landscape study of the site and of the integration of the project in the environment. The administrative service in charge of the project has to check its conformity with the town-planning documents.

9.2.5 Connection to the grid

The connection to the grid is a procedure different from the water right. It must be asked to the authority in charge of the concerned grid (high or low voltage depending on the power delivered).

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, in particular of wind farms. The connection capacity of the local grid may be saturated. In which case, in order to accept more connections it is necessary to reinforce the grid, which of course is much more expensive than a simple connection. And on the other hand, it is necessary to be sure, of which connections have to be planned, in order to avoid the reinforcement of the grid if it is not necessary.

To address this situation, France has introduced a system of queue. For each demand, a pre-study of the project is first done, at the end of this study, the utility gives an answer to the developer who then can ask for a detailed study of the connection of the plant. The price of this procedure can include the reinforcement costs, but a part of these costs will be reimbursed later if other producers use the equipments paid by the first developer.

9.2.6 Other procedures

Some other procedures include:

- *Land reclaiming authorisation.* A land planted with trees may have to be used as a way to access the plant, implant a water way, a penstock, etc... In these cases an authorisation may be necessary to reclaim the land, depending on the juridical status of the forest. The authority to be contacted is the one in charge of agriculture and forests.
- *Agreements of borders and land property:* A SHP developer is not always the owner of all the land necessary for the project. He may need to build a penstock, an access way or a part of a waterway on the land of a neighbour.

The developer will have to find an agreement with the neighbours concerned by the project. Where the Municipality is the developer they often have additional rights and powers above the private developer that they are at liberty to exercise. If no agreement is reached, the Municipality can insist that the landowner agrees in the public interest, something that private developer is not capable of enforcing.

9.3 Some practical examples⁵

9.3.1 Greece

According to the current Greek legal framework, three main licences are necessary for the building and operation of a RES-electricity plant:

- Electricity Generation Licence
- Installation Licence
- Operation Licence

The first of these is obtained at national level and it provides an initial approval that a certain project is possible. Generally, it is rather straightforward to obtain this licence if there are no "grey" points in the application. The Installation Licence is the most difficult of the three to obtain. The procedure is very complicated and involves a large number of entities. Recently (April 2003) a new Ministerial Decision (1726/2003) has been issued to simplify and accelerate the procedure for this licence.

The Operation Licence is issued after the completion of all construction works, and in a way certifies that the plant has been built according to the two other licences and the relevant studies submitted, and according to the existing legal framework in general.

9.3.1.1 **Electricity Generation Licence**

The acquisition of the "Electricity Generation Licence" is the first step on the road of acquiring all the necessary licences for building and operating a RES-electricity installation. This licence is issued by the Ministry of Development, following an opinion by the Energy Regulatory Authority. The application for this licence is accompanied by the following:

- General information about the entity seeking the license: legal name, address, names of directors of board (where applicable), organisation chart, etc.
- Recent financial statements, including the balance sheets and the income statements of the three most recent years
- Business plan, covering at least a period of five years
- Feasibility study.

9.3.2.2. **Installation licence**

- The procedure for acquiring this licence is the most complicated and time-consuming. For the issuing of the installation license for a RES-electricity project, the applicant should file an application with the Regional Authority. The format of this application is given by the Ministerial Decision 2000/2002. The holding of a valid Electricity Generation Licence is a requirement for filing the application. The application is accompanied by a number of supporting documents, studies, maps etc.

Although the Regional Authority is the "single point" for filing the application for the installation licence, this does not mean that the application is only processed internally in the Region's departments. On the contrary, the Regional Authority asks the opinion of numerous Services before

issuing the installation licence. Also, a number of other "intermediate" licences are required before the final decision.

The installation licence for small hydro projects has a validity period of two years. This means that the applicant has to complete the works within this period. An extension of one more year can be granted, provided that at least 70% of the works will have been completed.

Application Package

The application for the Installation Licence is filed together with the following:

- Certificate of exclusive use of the site.
- Technical Description
- Environmental Impact Study
- Maps and photos
- Solemn declarations
- Supporting Technical Description for the interconnection to the transmission system.
- Other supporting documents.

Advisory Authorities and Bodies for the Environmental Impact Appraisal

- In the process of issuing the Installation Licence, the Regional Authority also issues an "Approval of Environmental Terms and Conditions" which is a necessary prerequisite for the Installation License. For this Approval, which is based on the Environmental Impact Study submitted by the applicant, the Regional Authority asks for advisory opinions from a number of other Authorities and Bodies: Chief Forester's Office, City Planning Service, curators of Prehistoric and Classical Antiquities, Curators of Byzantine Antiquities and Curators of Modern Monuments, Civil Aviation Authority, Ministry of National Defence General Staff, Greek Telecommunications Organization, Greek National Tourism Organization.

Publicity procedure for the Environmental Impact Appraisal

- Before issuing the "Approval of Environmental Terms and Conditions" the Regional Authority has to publicize the application of the prospective RES investor. To this end, a copy of the application package is sent to the competent prefecture and municipal authorities. The authorities of the three levels (regional, prefectural and municipal) put a relevant notification on their bulletin boards and ask for any objection within a period of 30 days.

In case of objections, the proposed project is discussed in an open meeting of the prefectural or municipal council. The council submits its final comments and suggestions to the Regional Authority that finally decides on the environmental authorisation of the given project.

9.3.1.2 Operation Licence

This licence is granted by the Regional Authority, following completion of the construction works and after checking and certification by relevant Services of the project's compliance with all the terms and conditions concerning its installation and operation.

The application for the operation licence is submitted together with supporting documents.

9.3.2 France⁶

The French regulation distinguishes the projects less than 4 500 kW from those more than 4 500 kW. The first ones need an authorisation delivered by the *préfet*, the local representative of the government. The necessary procedure is described below. Where there are difficulties, this process may take up to five or ten years. Besides the 2001/77/EC Directive, the French government organised a debate on the simplification of procedures in RES projects. The main conclusion for SHP was that the procedure should not last more than 2 years.

Projects bigger than 4 500 kW need a concession which is granted by the Council of state. It has a maximum duration of 75 years and can be renewed in thirty years periods. Whereas the authorization may be precarious and eventually be repealed without indemnity in case of national defence, public safety, etc..., the concession gives the advantages of a public utility status, but its procedure is heavier. These projects need a high level of specialization and the concession procedure is not presented in this guidebook.

9.3.2.1 “Classified rivers”

An important point of the French regulation is that a part of the river network, classified by decrees in reference to the 16 October 1919 law, is forbidden to the energetic use. So, the developer has firstly to check if the site is not “classified”.

9.3.2.2 Authorisation procedure

According to the 16/10/1919 law, like the concession, the authorization is granted for a maximum of 75 years and can be renewed. In fact, this duration is now generally shortened to 30 years, so that at each renewal, the producer can comply with the new regulation.

The 95-1204 decree of 6/11/1995 specifies the documents and information to be supplied in the application file. They mainly include:

- Information on the developer
- A technical and geographical file of the project
- An **environmental impact assessment** for projects of raw maximum power more than 500 kW; if this power is less than 500 kW, a simpler study (“notice d’impact”) is enough
- Duration asked for the authorization
- Economic and financial information
- Land properties

The application file is to be sent to the *préfet* who forwards it to the service in charge of the police of water (SPE, “service chargé de la police des Eaux”). The SPE studies the file and transmits it to the regional public authorities: Direction régionale de l’industrie, de la recherche et de l’environnement (DRIRE), Direction régionale de l’environnement (DIREN), Conseil supérieur de la pêche (CSP). It can ask the developer for more information. After reception of the various opinions, the SPE forwards the file to the *préfet*. If the *préfet* agrees with the project, he passes a decree deciding a public inquiry.

After receiving the advice of the County Council, the Mayors and of all the concerned services, a water right is written and proposed by the SPE. The *préfet* takes his final decision. If he agrees, he signs an authorization *decree* and the works are executed. At the end of the works, the equipment is checked and the agreement of the public authority is given in a report of checking.

9.3.2.3 Connection to the grid

According to the law of the 10 February 2000 and its decrees, the grid has the obligation to buy the electricity generated by RES plants of capacity less than 12 MW, but the producer has to demonstrate that he cannot sell its production at a good price to another client and he must forward an application to the utility. For capacities less than 10 MW, the connection is done to the distribution grid (low voltage). For capacities upper than 10 MW, the plant is connected to the high voltage electricity transfer grid.

In parallel, the developer has two procedures to follow:

- An application of authorization to run the plant is to be sent to the ministry in charge of energy (2000-877 decree of 7 September 2000).
- A certificate of purchasing obligation is to be asked to the regional Direction of Industry.

9.3.3 Ireland

In Ireland, the procedures are as follows:

9.3.3.1 Planning Permission

The planning application consists of an application form and of several documents maps and plans. The planner must take all references to renewable energy in the Development Plan into account. Development Plans must be reviewed every 5 years.

The developer has to provide information on how the development will impact on the area. This is done via an Environmental Impact Statement (EIS). An EIS will also be required if the development is located in a National Heritage Area (NHA), Special Area of Conservation (SAC), Special Protection Area (SPA) or other designated areas.

An Environmental Impact Statement is legally defined in the Local Government (Planning and Development) Regulations, 1990. A typical EIS would contain examinations of the impact of the project on the following: Water, soils & geology, air quality, noise, flora & fauna, cultural heritage, electromagnetic fields, visual impact, climatic effects, interaction of impacts, alternatives. An EIS will decide whether the application is successful or not. It needs to be clear, thorough and cover all areas of interest to the planner. Planners, and officers from the statutory bodies, are available to provide advice on scooping an EIS.

9.3.3.2 Electricity Regulation Agreements

There are two agreements to be arranged:

1. Licence to Construct. Anyone wishing to construct a new generating station or reconstruct an existing generating station must obtain an Authorisation to Construct under Section 16 of the Electricity Regulation Act, 1999.
2. Generators Licence. Under Section 14 (1) (a) the Electricity Regulation Act, 1999, the Commission has powers to grant, or refuse to grant, a Licence to Generate Electricity.

There is a streamlined application process, for both licences, for developments under 5MW. The commission must be satisfied that the development meets the criteria below in order to grant a licence. However, discussions are underway regarding exemptions from these licences for smaller developments:

- Will not impact adversely on grid capacity or stability
- Is financially viable
- Observes environmental standards

9.3.3.3 Power Purchase Agreements (PPA)

In order to arrange finance from a bank, the developer will have to demonstrate a guaranteed purchaser for his electricity for a number of years. There are currently two main ways of doing this:

1. Alternative Energy Requirement (AER) programme. This is a competition organised by the government, who awards contracts to individual generators. These contracts require the Public Electricity Supplier to purchase the electricity at a set price for 15 years. There is significant competition for these contracts and there is no guarantee of being granted one.
2. Third Party Access: It is possible to come to an arrangement with a supplier in the electricity market, who would give the developer a contract guaranteeing that they will purchase the electricity at a given price for a given period. These can also be quite competitive and will not be significantly higher than the AER prices.

9.3.4 Austria

The first administrative step should be discussion with the responsible experts at the governmental body. The developer has to write what amounts to a pre-feasibility with the main decisions (river, location, head, discharge, system, power, production etc.) and to present it to the government. This is a pre-check to avoid collision with possible other projects or general position of the government.

After passing that step usually a so-called "wasserrechtliches Einreichprojekt" (a project prepared to get the right to building the site) is prepared. Compared with the pre-feasibility it gives all the necessary details. That project is the basis for the negotiations within the granting procedure. A main part of this procedure is the public discussions. Within this step people involved (including fishermen etc.) can say what they want or what they do not want. The chairman of this meeting has to collect all the opinions and finally find a decision whether the project can be built or not.

The next step is related to the environmental law. Although ecological items are included in the "water right" there might be additional demands and a separate procedure. The license will be valid for at least 30 years but longer periods can also be asked for. There is no "water fee" (Wasserzins) to be paid.

A good preparation of the project and co-operating with those responsible for the governmental evaluation is of highest importance. This preparation has to include several talks, serious ecological management (proposed by an additional expert, being part of the team). Up to now there are no "forbidden rivers" although in some cases everybody knows, that a project would never get a license – there are implicit forbidden rivers.

There is no general rule about residual flow. Usually the value varies between NNQ (lowest low flow) and MNQ (mean low flow). In many cases it makes sense to make a short individual study. Without this the governmental experts are able to provide their position without specific information, the result of which is often cautiously high - very much higher than the result of the study, so it can be worth the expense.

9.3.5 Portugal

The Portuguese administrative procedure flowchart below is given by way of example. The main steps of the administrative process to fulfil exploitation of a SHP scheme and to achieve independent production of electricity (production in special regime) are represented in this flowchart - it considers the grant of the four fundamental licences:

- Licence of Construction of Hydraulic Works.
- Licence of Establishment.
- Licence of Water Use.
- Licence of Exploitation.

Due to informational purposes, the necessary taxes and guarantees for the development of the process are included, except the ones related to the General Directorate for Energy, which represent much lower financial costs.

In the chart does not address the question of SHP development in an environmental sensitive area (e.g. Natura 2000 Network), it is considered that the costs of the EIA process (Environmental Impact Assessment) are not compatible with the relatively small budgets of SHP with a lower capacity than 1 MW. In the flowchart of the process development the request for the Reception Point made to General Directorate for Energy was inserted as a consequence of the granting of the Dispatch of the Regional Direction for the Ministry of Environment - though this specific situation is not addressed by the legislation.

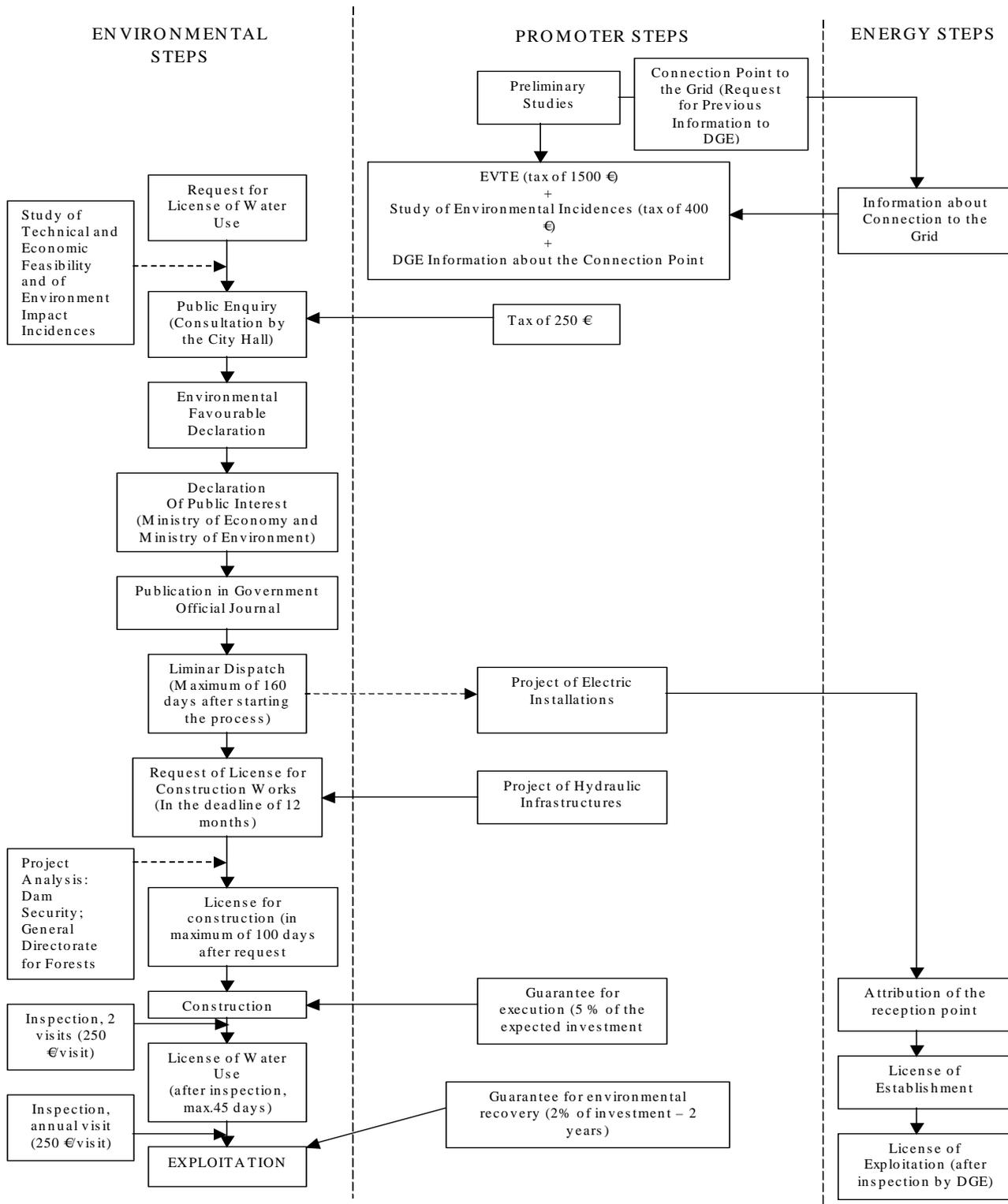


Figure 9.2: Portuguese administrative procedures flowchart

9.3.6 Poland

The procedure includes four main stages:

Stage 1

Application to the Water Authority (*Regionalny Zarząd Gospodarki Wodnej, RZGW*) An initial approach is made to the Water Authority in which a site is proposed as a possible location. The Water Authority considers this and then gives a decision. If **general approval** is given, this will outline the general conditions that are needed.

Stage 2

Application to the Gmina in which the proposal is situated. A more detailed proposal is made to the local *Gmina* (the municipality). This is an application for the *WZIZT (Warunki Zabudowy I zagospodarowania terenu* – Conditions for Construction and management of land). This proposal gives basic data about the investment (size, where exactly located, what changes this will make to the land etc.). The Gmina considers this in relation to its planning documents and policies (in particular its local plan) and then issues a decision including the relevant conditions

Stage 3

An application is made to the *Powiat* (District Authority). This will award the *Operat wodno-prawny* (Water and Legal Operating permission). This is the key document and to obtain this all the data about the investment need to be produced. The document is very detailed and also contains the approval of the water authority which can change its opinion at this stage should it so decide. Information to be provided includes a business plan, and environmental assessment and detailed maintenance arrangements and so on. Following this the *Powiat* gives the developer a *Pozwolenie na budowę* (Building permit) in it says who will have to approve the construction after completion. They have complete freedom in this – it can be anyone even the local chimney sweep. Following this a new application has to be made to the Water Authority, *Gmina* and *Powiat* to get permission to start operating.

Stage 4

Connection to the networks. Negotiation of conditions of access to the network and contracts for sale are carried out separately and can be very difficult. Normally a prediction of daily production expected and hourly production schedules are required and fines are levied if the producer does not keep to his predictions.

9.3.7 Switzerland

As any federal State, Switzerland has rules, which vary from one canton to another. Nevertheless the procedures are similar and a certain number of federal laws apply:

- Law on the protection of water: http://www.admin.ch/ch/f/rs/c814_20.html (residual flows)
- Law on energy: http://www.admin.ch/ch/f/rs/c730_0.html (access to the network and buy-back conditions)
- Law on the hydraulic forces: http://www.admin.ch/ch/f/rs/c721_80.html (regulation of the concessions)

They are the principal laws fixing the legislative framework in Switzerland for the hydroelectric power stations, the small ones in particular.

In addition, the new law on the nuclear energy which will come into effect amends the law on energy as it introduces a compensation fund taken from the high voltage transmission to finance the preferential rates granted to the energy producers from SHP.

The granting of the concession can be of cantonal (canton of Vaud for example), communal (it is the case in Valais) or bourgeoisiale (in some cantons) competence. There is no request for concession, which goes up at the federal level. On the other hand, there is an authority for the supervision of great installations.

The plants using drinking water and wastewater do not need concessions. In general, a simple authorization of the canton is enough. It is not systematic.

The normal procedure is given in the chapter 7 of the document “Introduction to the construction and the exploitation of SHP”. This document is downloadable on: http://www.smallhydro.ch/français/download/download_f.htm

For more information, contact the federal energy office (<http://www.suisse-energie.ch/internet/02007/index.html?lang=fr>)

Appendix A gives a general overview of the current legislative framework that the small hydropower sector has to comply with at European level.

APPENDIX A: SMALL HYDROPOWER IN THE INTERNAL ELECTRICITY MARKET

INTRODUCTION

The European electricity sector is moving away from a monopoly on generation toward a competitive market in which customers will have the opportunity to choose among power suppliers. That is already happening in some Member States (MS) of the European Union (EU) like Austria, Denmark, Finland, Germany, Spain, Sweden and the UK (where the declared market opening is of 100%)⁷ and shortly it will happen in all of them. We are moving away from complex regulatory schemes toward greater reliance upon market mechanisms. One essential element of the new market rules is to ensure that those rules drive the restructured market toward cleaner resources that are compatible with the public interest. Climate scientists overwhelmingly agree that greenhouse gases are responsible for the Climate Change and that serious damage to the earth's environment will result, with enormous consequences for humanity. Furthermore the EU has to comply with the Kyoto Protocol and improve the security of energy resources supply, using indigenous renewable resources to reduce our dependence upon imported fuels.

In this new context, the market position of the European small hydropower sector depends on the legislative framework in force in the EU. There are mainly two relevant legislative pieces:

- Directive 2001/77/EC for the promotion of electricity from renewable energy sources (RES), know as the RES-E Directive. It sets the legal framework applicable in all MS for the promotion of electricity generated from RES establishing an ambitious target of doubling the contribution of RES to the gross inland consumption by 2010 in the EU.
- Directive 2003/53/EC concerning common rules for the internal market in electricity which establishes common rules for the generation, transmission, distribution and supply of electricity. It lays down the rules relating to the organisation and functioning of the electricity sector, access to the market and the operation of the systems among others.

Within this legislative framework, there are three aspects which concern the small hydropower sector in particular: (i) targets settled in the legislation and the difficulty to achieve them, (ii) tariff structures and support schemes currently in force and their effectiveness and (iii) barriers still standing despite the new favourable legislative framework.

A.1 TARGETS

The RES-E Directive establishes national indicative targets for the contribution of electricity from RES to gross electricity consumption by 2010 in each MS. However, it does not give any indication for the contribution of each RES to the total objective, letting this decision to each MS. Although this is totally according to the definition of a Directive and the subsidiarity principle, it could create unhealthy competition between the different RES. Table A.1 shows the indicative national targets for each MS settled in the Directive.

Table A.1: Reference values for Member States' national indicative targets for the contribution of electricity from renewable energy sources to gross electricity consumption by 2010

	RES-E TWh 1997	RES-E TWh 1997	RES-E % 2010
Belgium	0.86	1.1	6.0
Denmark	3.21	8.7	29.0
Germany	24.91	4.5	12.5
Greece	3.94	8.6	20.1
Spain	37.15	19.9	29.4
France	66.00	15.0	21.0
Ireland	0.84	3.6	13.2
Italy	46.46	16.0	25.0
Luxembourg	0.14	2.1	5.7
Netherlands	3.45	3.5	9.0
Austria	39.05	70.0	78.1
Portugal	14.30	38.5	39.0
Finland	19.03	24.7	31.5
Sweden	72.03	49.1	60.0
United Kingdom	7.04	1.7	10.0
European Community	338.41	13.9	22

In October 2003, MS will start to report to the European Commission about their national strategy on how to reach the foreseen target according to the different RES. Once the national legislation establishes concrete objectives for the short-medium term by type of technology, an assessment of RES-E directive effectiveness for the small hydropower (SHP) sector can be carried out.

Nevertheless, The White Paper for a Community Strategy and Action Plan COM (97) 599 final (26/11/97) set up a concrete and ambitious target for small hydropower of about 14 000 MW of install capacity by the year 2010. As shown in figure A.1, applying the average annual growth rate of the last years up to the year 2010, the European small hydraulic capacity would remain in the neighbourhood of 12 000 MW but is generally agreed that the target still could be achieved if the regulatory framework were streamlined.

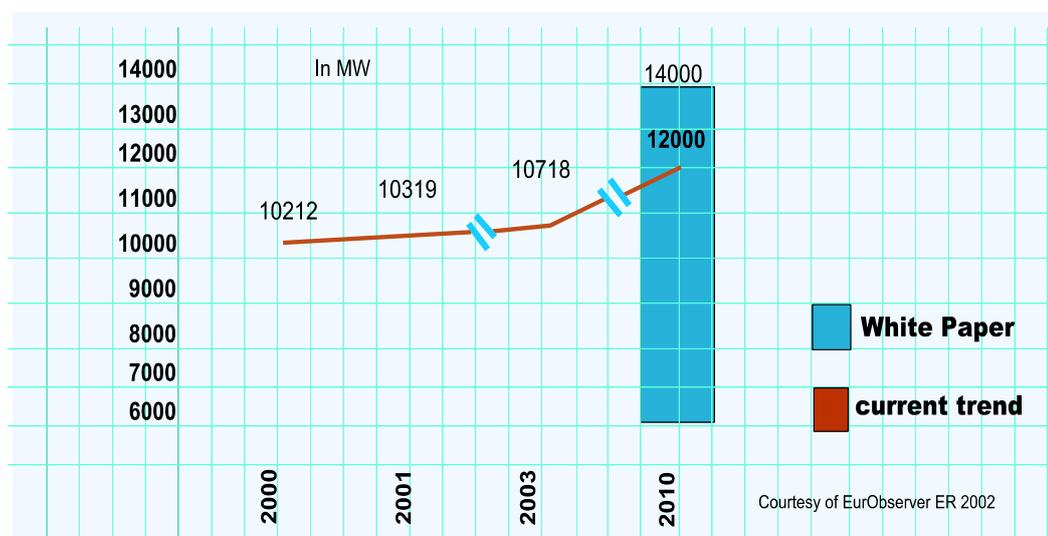


Figure A.1: SHP current trend and White Paper targets

According to the national SHP associations, the slowness of small hydropower development in recent years is not, in most cases, due to economic reasons but to the existence of significant administrative and environmental obstacles. Although the definition of an adequate small hydropower economic support framework is a condition, sine qua non, it is not enough to promote the development thereof. If the Commission wish to design a complete small hydropower support policy it will have to include among its priorities the removal of the administrative and environmental barriers that are blocking development and have, at least, the same importance as that with which is given to the creation of a common compensatory framework.

A.2 TARIFF STRUCTURES & SUPPORT SCHEMES

The promotion of renewables, aimed at increasing their share in the fuel mix, notably by ensuring efficient and appropriate support schemes is at the core of the EU energy policy objectives: security and diversity of supply, competitiveness and environmental protection. Besides, RES will need support in the short and medium term to develop and fulfil Kyoto commitments. The reasons for the need of support are basically linked to two elements:

- **Cost.** The biggest disadvantage of RES at the moment is that under the current framework conditions, characterised by the non-internalisation of external costs of energy production, costs tend to be significantly higher than those of conventional sources of energy. It is generally acknowledged that conventional energy sources not only do not pay their full external costs, but also on top of that are strongly subsidised. Research conducted for the EU in the ExternE project shows that the cost of electricity generated from coal and oil in the EU would on average double if external costs to environment and health were included. The result is that electricity generated with renewable energy sources cannot compete on a free market with the conventional one. Consequently, it appears correct to conclude that in order to develop positively, renewable generated electricity requires two essential elements: (i) a price support mechanism that enables renewables producers to enter the market and make a reasonable profit

and (ii) a stable regulatory environment such that investors can enter the market without concern that the price support mechanism will be modified in a unprofitable way.

- Infrastructure. Renewable generators have a number of important challenges that need to be addressed like planning or grid connection issues. The future of RES-E will most likely depend on a combination of prices and political support. Ending distortion by removing subsidies for conventional generation and internalising external costs would go a long way. The problem of external costs could be corrected within the EU e.g. by a carbon tax, at least with regard to fossil fuels. According to APPA (the Spanish Association of Renewable Independent Producers) the external costs of conventional electricity generating sources should be considered an essential element of reference in order to quantify the compensation that must be received by small hydropower electricity in terms of compensation for its environmental and social benefits

Member States have been supporting RES in one or more ways, via Research and Development (R&D), tax reductions/exemptions, guaranteed prices, investment subsidies and the like. The Commission itself has been supporting for over a decade R&D in the field of renewables in the scope of the different Framework Programmes for Research and Development (FPs), six up to now. Nevertheless, thanks to the White Paper and specially RES-E Directive, policy instruments to encourage investment in the production of electricity from RES have been developed in the EU. It is clear that without a tariff's framework that could guarantee the predictability of the investment's remuneration RES-E technologies, shall not achieve the targets indicated in the legislative framework. The RES-E directive defines renewable energy sources as non-fossil energy sources - the original proposal limited hydropower to plants up to 10 MW of installed capacity, but this provision was eliminated in the final draft. Some MS, like Spain, has a feed in tariff for the electricity generated in plants with an installed power from 10 to 50 MW, although the premium decreases with the increase of capacity. Other MS increase the support to the smaller plants by decreasing the value of the premium when production increases. An example is Austria, where the first GWh generated on a new plant is paid at 5.96 cts € the next 3 GWh at cts €4.58 and once exceeded the 24 GWh at 3.31 cts € A complete detailed picture of the tariffs applicable for small hydropower in the EU is given in chapter 8. The EC Directive on common rules for the internal market in electricity also underlines the priority of generation installations using renewable energy sources.

The policy instruments that are in place in the different Member States are all based on two main principles. As figure A.2 shows, the instruments either affect the supply or the demand of renewable electricity, and the focus either on the production of electricity or on the installed capacity of renewable electricity plants.

Within this categorisation, there are basically three main instruments to promote renewable electricity. These instruments are (i) feed-in tariffs, (ii) quota obligations in combination with a green certificate system and (iii) tendering/bidding schemes. Besides the three main instruments there are complementary mechanisms possible, like investment subsidies and fiscal measures.

At the time the RES-E Directive was drafted, the Commission was favourable to adopt the tendering scheme, made popular at that time by the UK NFFO programme but in the final proposal it decided to leave free the choice of support to the Member States. Therefore the Directive does not indicate which set of policy instruments would be favourable. As result, MS continue to develop their own national mix of policy instruments to stimulate renewable electricity.

Generation based (kWh)	
Supply side	Demand side
Feed-in tariffs	Quota obligations /
Fiscal measures	Green certificates
Bidding systems	(Fiscal measures)
(Subsidies)	(Quota obligations)
Investment subsidies	(Quota obligations)
(Fiscal measures)	(Quota obligations)
Capacity based (kW)	

Source: Renewable electricity policies in Europe. Country fact sheets 2003, ECN

Figure A.2: RES support policy instruments

- Investment Subsidies:** Authorities offer subsidies on investment for RES-E technologies, in general in terms of % of the Total Investment. This type of support can help to overcome the barrier of a high initial investment and it is commonly used to stimulate investments in less economical renewable energy technologies.
- Feed-in Tariffs:** Operating currently in several EU Member States, (notably Germany and Spain), they are characterised by a specific price being set for RES-E that must be paid by electricity companies, usually distributors, to domestic producers of RES-E. In a variant of the system the government sets a fixed-premium paid above the normal or spot electricity price, to RES-E generators. The fixed price or fixed premium may be revised by the government to reflect falling costs of the technology.
- Quota Obligation Systems and Green Certificates:** Quota obligations are used to impose a minimum production or consumption of electricity from RES. The government sets the framework within which the market has to produce, sell or distribute a certain amount of energy from renewable sources. The obligation is imposed on consumption or production. The quota can usually be traded between companies to avoid market distortions. A Tradable Green Certificate (TGC) is needed for this system. Operating notably in Ireland and The Netherlands, and foreseen for introduction in Denmark and Flanders, the producers sell electricity in the open market, but at the same time receive a “Green Certificate” per MWh produced, which is traded separately from the physical commodity. The value of the TGC comes as the result of the obligation, placed on all consumers to purchase a certain amount of green certificates from RES-E producers according to a fixed percentage, or quota, of their total electricity consumption/production. Since consumers wish to buy these certificates as cheaply as possible, a secondary market of certificates develops where RES producers compete with one-another for the sale of the green certificates.

- **Tendering schemes and bidding systems:** Historically operating in the United Kingdom under the NFFO agreements but no longer in place, prospective RES-E generators submit competitive bids for fixed-price contracts offered by authorities. The system is combined either with feed-in tariffs or TGCs. In UK, where this system operated with some technologies, the TGCs are known as ROCs (Renewable Obligation Certificates). Bidding procedures can be used to select beneficiaries for investment support or production support or for other limited rights. Potential investors or producers have to compete through a competitive bidding system. The criteria for the evaluation of the bids are set before each bidding round. The government decides on the desired level of electricity from each of the RES, their growth rate over time and the level of long-term price security offered to producers over time. The bidding is accompanied by an obligation on the part of electricity providers to purchase a certain amount of electricity from renewable sources at a premium price. The difference between the premium and market price is reimbursed to the electricity consumption. In each bidding round the most cost-effective offers will be selected to receive the subsidy. The mechanism therefore leads to the lowest cost option.
- **Fiscal measures:** Some MS like Austria, Belgium, Denmark or Portugal support renewable electricity by means of fiscal system. These schemes may take different forms, which range from rebates on general energy taxes, rebates from special emission taxes, proposals for lower VAT rates, tax exemption for green funds to fiscal attractive depreciation schemes, which must be in line with the Community guidelines on State aid for environmental protection.

Concerning SHP, table A.2, elaborated recently by ESHA, shows the support systems adopted by the different Member States and currently in force. Prices generated by these support systems or buy-back prices are detailed in chapter 8.

No significant changes will take place in the medium term in the Member States, but there is still uncertainty about that possibility. In Denmark, one of the original supporters of the feed-in tariffs for wind energy, the introduction of a TGC system has been announced and postponed several times, and still there is a large uncertainty on the planned introduction in 2004. In Ireland, the government has announced the intention to release a consultation document in the first quarter of 2003 with the objective to set new targets for the RES-E technologies in the year 2010, and to examine alternative measures for supporting them. In Spain the feed-in tariffs will probably remain for years although investors demand clearer rules in the determination of the future premium prices. In Austria after the negative experience with the tradable green certificate system for small hydro it is unlikely that the feed-in tariffs support scheme will change now that a certain harmonization at state level has been achieved. In Germany, the Federal Environment Ministry published an amendment to the Renewable Energy Law (in 2003) with the request for comments. The proposal still supports the feed in tariff scheme as the preferred instrument to reach the 2010 target, but introduces more differentiated tariffs, some lower and some higher than those of the present law. No significant changes are expected in the other countries. RES-E producers try to limit the price uncertainty, in the feed tariff system, requesting the authorities to issue transparent rules that determine the premium for the next years.

The RES-E Directive – Art 4, paragraph 2 -, puts an obligation on the Commission to present, not later than 27 October 2005, a well-documented report on experience gained with the application and coexistence of the different mechanisms of support. The report shall assess the success of the support systems in promoting the consumption of electricity produced from renewable energy. This report shall, if necessary, be accompanied by a proposal for a Community framework with regard to support schemes for electricity produced from renewable energy sources. Any such proposal must include a transitional period of at least seven years, this means that no mandatory unified system will be in force until 2012.

Table A.2: SHP current support systems used in EU Members States

Member State	Compensation Scheme
Belgium	Wallonia: Green certificates since 1 st October 2002 Flanders: Green certificates since 1 st January 2003
Denmark	Transition period from fixed price to green certificates.
Germany	Feed-in tariff
Greece	Feed-in tariff
Spain	Fixed price (feed-in tariff) and premium payment adjusted annually by government.
France	Feed-in tariffs applicable only to renewable plants up to 12 MW. Price paid to SHP plants depends on their construction date. Winter tariff for SHP plants commissioned after 2001 is guaranteed for 20 years.
Ireland	Public tender: Alternative Energy Requirement (AER) competitions. The Irish Government launched in February 2003 the AER VI.
Italy	Quota + tradable green certificates: The quota should increase by 0.3% each year starting from 2005. The grid authority fixes a cap (upper) price for green certificates every year. Certificates are issued only for the first eight years of operation.
Luxembourg	Feed-in tariff. Premium is guaranteed for 10 years.
Netherlands	New support system as from 1 st July 2003. Wholesale electricity market and feed-in premium. Hydropower does not receive green certificates.
Austria	Feed-in tariff: a) Old plants: Plants which obtained planning permission before January 1 st 2003, including all those currently operating, are entitled to receive the guaranteed feed-in tariff for the first 10 years of operation. b) New plants: Plants obtaining all planning permissions between January 1 st 2003 and December 31 st 2005 and which start generating by the end of 2006 are entitled to receive the feed-in tariff for the first 13 years of operation.
Portugal	Feed-in tariff
Finland	Nordpool market plus premium
Sweden	Green certificates: This system was started May 1 2003.
United Kingdom	Market price (energy market – NETA) and Renewable Energy Obligation Certificates – ROC's (only available for Hydropower up to 20MW when they have been built since 1990 or if built before 1990 have been refurbished with new turbine runners and control equipment. Also hydro plants commissioned since 2000 are also eligible for ROC's

A.3 BARRIERS

One major barrier to the further development of RES electricity in the EU is the administrative and planning procedures that potential generators must meet. This has been highlighted by ESHA on behalf of a large number of representative organisations responsible for the small hydro producers. It should be noted that these rules, often developed for both large generation projects and small RES projects alike, place a significant burden on RES producers given their smaller size, both overall and in terms of average generation site.

The planning procedures vary significantly among Member States, regions and projects. Articles 4-6 of the RES-E Directive provide the basic rules in this respect, notably that where an authorisation procedure is followed, the rules must be objective and non-discriminatory. In the BlueAge study carried out on behalf of ESHA and partially funded by the Commission, the length of the authoritative procedures was estimated from 12 weeks in Scotland to two years in Italy and 4 years in Spain. But what is more significant is that in almost every MS of the EU only a few dozens of permissions have been granted recently. Without authorizations no development is possible and therefore support schemes favouring competitive prices become useless, not only to promote SHP but also to achieve 2010 objectives.

RES-E Directive suggests that an effort is necessary to make progress in this area and propose to require all Member States:

- To review the existing measures, planning and administrative, that potential RES producers must meet, to determine which action, if any, can be taken to reduce the regulatory barriers to increasing RES production such as:
 - ⇒ The setting up of a single reception point for authorisation applications,
 - ⇒ Ensuring co-ordination between the different administrative bodies involved and the establishment of reasonable deadlines,
 - ⇒ The establishment of a “fast-track” planning procedure for RES producers,
 - ⇒ Where applicable, the possibility of establishing mechanisms under which the absence of a decision by the competent bodies on an application for authorisation within a certain period of time automatically results in an authorisation,
 - ⇒ The production of specific planning guidelines for RES projects,
 - ⇒ The identification, at national, regional or local level, of sites suitable for establishing,
 - ⇒ New capacity for generating RES electricity,
 - ⇒ The introduction of training programmes for the personnel responsible for the authorisation procedures.
- To publish a report in this respect, outlining the conclusions reached as to what action, will be taken, no later than two years following the entry into force of the Directive. The Commission

would, on the basis of the Member States reports, present a report on the experience of Member States, highlighting best practice.

Directive 2003/54/EC concerning common rules for the internal market in electricity suggest also some measures on this respect. For example:

- In the preamble of the Directive it is mentioned that:
 - ⇒ To avoid imposing a disproportionate financial and administrative burden on small distribution companies, Member States should be able, where necessary, to exempt such companies from the legal distribution unbundling requirements.
 - ⇒ Authorisation procedures should not lead to an administrative burden disproportionate to the size and potential impact of electricity producers.
 - ⇒ Nearly all Member States have chosen to ensure competition in the electricity generation market through a transparent authorisation procedure. However, Member States should ensure the possibility to contribute to security of supply through the launching of a tendering procedure or an equivalent procedure in the event that sufficient electricity generation capacity is not built on the basis of the authorisation procedure. Member States should have the possibility, in the interests of environmental protection and the promotion of infant new technologies, of tendering for new capacity on the basis of published criteria. New capacity includes inter alia renewables and combined heat and power (CHP).
- Article 3 about public service obligations and customer protection mentions that:
 - ⇒ Member States shall ensure, on the basis of their institutional organisation and with due regard to the principle of subsidiarity, that electricity undertakings are operated in accordance with the principles of this Directive with a view to achieving a competitive, secure and environmentally sustainable market in electricity, and shall not discriminate between these undertakings as regards either rights or obligations.
 - ⇒ Having full regard to the relevant provisions of the Treaty, in particular Article 86 thereof, Member States may impose on undertakings operating in the electricity sector, in the general economic interest, public service obligations which may relate to security, including security of supply, regularity, quality and price of supplies and environmental protection, including energy efficiency and climate protection. Such obligations shall be clearly defined, transparent, non discriminatory, verifiable and shall guarantee equality of access for EU electricity companies to national consumers. In relation to security of supply, energy efficiency/demand-side management and for the fulfilment of environmental goals, as referred to in this paragraph, Member States may introduce the implementation of long term planning, taking into account the possibility of third parties seeking access to the system.
 - ⇒ Member States shall ensure that electricity suppliers specify in or with the bills and in promotional materials made available to final customers the contribution of each energy source to the overall fuel mix of the supplier over the preceding year and at least the reference to existing reference sources, such as web-pages, where information on the environmental impact, in terms of at least emissions of CO₂ and the radioactive waste resulting from the electricity produced by the overall fuel mix of the supplier over the preceding year is publicly available.

- ⇒ Member States shall implement appropriate measures to achieve the objectives of social and economic cohesion, environmental protection, which may include energy efficiency/demand-side management, measures and means to combat climate change, and security of supply. Such measures may include, in particular, the provision of adequate economic incentives, using, where appropriate, all existing national and Community tools, for the maintenance and construction of the necessary network infrastructure, including interconnection capacity.
- ⇒ Member States shall, upon implementation of this Directive, inform the Commission of all measures adopted to fulfil universal service and public service obligations, including consumer protection and environmental protection, and their possible effect on national and international competition, whether or not such measures require a derogation from this Directive. They shall inform the Commission subsequently every two years of any changes to such measures, whether or not they require derogation from this Directive.
- Article 6 on authorisation procedure for new capacity underlines that:
 - ⇒ The authorisation procedures and criteria shall be made public. Applicants shall be informed of the reasons for any refusal to grant an authorisation. The reasons must be objective, non discriminatory, well founded and duly substantiated. Appeal procedures shall be made available to the applicant.
- Article 7 on tendering for new capacity mentions that:
 - ⇒ Member States may ensure the possibility, in the interests of environmental protection and the promotion of infant new technologies, of tendering for new capacity on the basis of published criteria. This tender may relate to new capacity or energy efficiency/demand-side management measures. A tendering procedure can, however, only be launched if on the basis of the authorisation procedure the generating capacity being built or the measures being taken are not sufficient to achieve these objectives.

THE ISSUE OF GRID CONNECTION AND ACCESS TO THE NETWORK

With the exception of isolated schemes, the plant cannot be operated without connection to the grid. Specifications for connection to the grid can also be a deterrent to the development of SHP and/or affect the viability of a scheme. Utilities that require unreasonable or unnecessary specifications or conditions (locating the connection point far away from the plant) strongly affect the feasibility of a scheme. In any case, utilities should guarantee a certain quality in their service, therefore asking for certain requirements from the independent producer to be connected to the grid.

The RES-E Directive in Art 7 states that “without prejudice to the maintenance of the reliability and safety of the grid, Member States shall take the necessary measures to ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources. This is of particular importance for RES-E being often small projects and, thus economically vulnerable towards interruptions in feeding in their electricity. They may also provide for priority access to the grid system of electricity produced from renewable energy sources. When dispatching generating installations, transmission system operators shall give priority to generating

installations using renewable energy sources insofar as the operation of the national electricity system permits". The Directive demands that Member States require the transmission system operators and distribution system operators to set up and publish their standard rules relating to the bearing of costs of technical adaptations, such as grid connections and grid reinforcements, which are necessary in order to integrate new producers feeding electricity produced from renewable energy sources into the interconnected grid and even to bear in full or in part the cost of the grid connections and grid reinforcements. The question of who has to pay for these grid-strengthening investments may affect the rate of uptake of RES-E in general. It should be noted that the Electricity Directive in Article 7(2) provides that Member States must ensure that technical rules and operational requirements concerning the connection of generators to the transmission grid are developed in an objective and non-discriminatory manner and are published.

Directive 2003/54/EC concerning common rules for the internal market in electricity is more precise and strict on this respect. For example, in the preamble when talking about the benefits of the internal market it is clearly stated that: "However important, shortcomings and possibilities for improving the functioning of the market remain, notably concrete provisions are needed to ensure a level playing field in generation and to reduce the risks of market dominance and predatory behaviour, ensuring non-discriminatory transmission and distribution tariffs, through access to the network on the basis of tariffs published prior to their entry into force, and ensuring that the rights of small and vulnerable customers are protected and that information on energy sources for electricity generation is disclosed, as well as reference to sources, where available, giving information on their environmental impact. The main obstacles in arriving at a fully operational and competitive internal market relate amongst other things to issues of access to the network, tarification issues and different degrees of market opening between Member States. For competition to function, network access must be non-discriminatory, transparent and fairly priced. In order to complete the internal electricity market, non-discriminatory access to the network of the transmission or the distribution system operator is of paramount importance. A transmission or distribution system operator may comprise one or more undertakings."

It also underlines that: "The maintenance and construction of the necessary network infrastructure, including interconnection capacity and decentralised electricity generation, are important elements in ensuring a stable electricity supply. The respect of the public service requirements is a fundamental requirement of this Directive, and it is important that common minimum standards, respected by all Member States, are specified in this Directive, which take into account the objectives of common protection, security of supply, environmental protection and equivalent levels of competition in all Member States. It is important that the public service requirements can be interpreted on a national basis, taking into account national circumstances and subject to the respect of Community law."

Several articles in the directive deal directly with the access to the network, access to the grid and new capacity:

- Article 5 on technical rules specifies that "Member States shall ensure that technical safety criteria are defined and that technical rules establishing the minimum technical design and operational requirements for the connection to the system of generating installations, distribution systems, directly connected consumers' equipment, interconnector circuits and direct lines are developed and made public. These technical rules shall ensure the interoperability of systems and shall be objective and non discriminatory. They shall be notified to the Commission in accordance with Article 8 of Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the

provision of information in the field of technical standards and regulations and of rules on Information Society Services”.

- Article 6 on authorisation procedure for new capacity underlines that “Member States shall lay down the criteria for the grant of authorisations for the construction of generating capacity in their territory. These criteria may relate to, among others: protection of public health and safety, protection of the environment and energy efficiency”.
- Article 14 on tasks of the Distribution System Operator is very explicit as regards RES, “A Member State may require the distribution system operator, when dispatching generating installations, to give priority to generating installations using renewable energy sources or waste or producing combined heat and power. Where distribution system operators are responsible for balancing the electricity distribution system, rules adopted by them for that purpose shall be objective, transparent and non discriminatory, including rules for the charging of system users of their networks for energy imbalance.”

Commission shall monitor and review the application of this Directive and submit an overall progress report to the European Parliament and the Council before the end of the first year following the entry into force of the Directive (this Directive is already in force since August 2003 and should be transpose into national law by 1 July 2004 at the latest), and thereafter on an annual basis. The report shall cover at least, among other things, the experience gained and progress made in creating a complete and fully operational internal market in electricity and the obstacles that remain in this respect, including aspects of market dominance, concentration in the market, predatory or anti-competitive behaviour and the effect of this in terms of market distortion. The Commission shall, no later than 1 January 2006, forward to the European Parliament and Council, a detailed report outlining progress in creating the internal electricity market. The report shall, in particular, consider the *existence of non-discriminatory network access*.

A.4 EU CURRENT INTERNAL MARKET

The latest report from the European Commission about the advances and success of the implementation of the internal electricity market in the EU shows that the situation is as follows:

- Implementation of the Electricity Directive. Although progress has been made in the electricity sector since 2001 in terms of general functioning of the market, there are still some areas causing particular difficulties:
 - ⇒ Differential rates of market opening are reducing the scope of benefits to customers from competition.
 - ⇒ Disparities in access tariffs between network operators, which due to the lack of transparency may form a barrier to competition.
 - ⇒ High level of market power among existing generating companies which impedes new entrants.
 - ⇒ Insufficient interconnection infrastructure between Member States.
- Results of market opening for customers. The two immediate consequences of market opening are a normal decrease of electricity prices and a free opportunity to switch and negotiate

supplier. Nevertheless, the trend of the electricity prices since 1999 is not remarkably downwards in the EU. The trend varies depending on the country with some MS experiencing rising prices and the falling effect is more remarkable in large consumers (industry) than in smaller ones (households). As far as concerns switching and renegotiating suppliers, in almost all MS, the majority of large eligible customers have taken the opportunity to explore alternative suppliers. For smaller customers it is of particular note that customers switching in Germany and Austria have increased.

- Public service issues. Member States are aware of the need to ensure security of supply, to deliver high levels of services to all customers and to defend the Community’s environmental objectives. Key issues being addressed in MS include, among others, measures to increase the share of renewable energy.
- Access to networks. Two issues affect the effective access to the network:

⇒ Network Tariffs: There is a wide variation between Member States in terms of the number of companies operating the different parts of transmission and distribution network. This is, in most cases, a legacy of how electricity supply was organised prior to market opening. In some cases such as in France, Ireland and Greece, there is a single national company that owns both the transmission and most or all of the distribution system at national level. In other cases, like Germany and Austria, transmission systems are operated on a regional basis, with distribution based on numerous individual municipal areas. Other Member States fall in between these two extremes in terms of the number of system operators.

Table A.3: Network access in the EU, electricity

TOTAL NETWORK TARIFFS	Number of transmission companies	Number of distribution companies	Medium Voltage		Low voltage	
			Estimated average charge (€/MWh)	Approx. range high-low (€/MWh)	Estimated average charge (€/MWh)	Approx. range high-low (€/MWh)
Austria	3	155	20	15-25	65	50-80
Belgium	1	33	15	n.a.		
Denmark	2	77	15	n.a.	25	unknown
Finland	1	100	15	10-20	35	unknown
France	1	172	15	n.a.	50	n.a.
Germany	4	880	25	15-45	55	40-75
Greece	1	1	15	n.a.		
Ireland	1	1	10	n.a.	40	n.a.
Italy	1	219	10	n.a.		
Luxembourg	-	15	20	n.a.		
Neth	1	18	10	unknown	35	unknown
Portugal	1	3	15	n.a.		
Spain	1	297	15	n.a.	45	n.a.
Sweden	1	248	10	5-15	40	20-60
UK	4	15	unknown	10-15	40	30-50

Source: Second benchmarking report on the implementation of the internal electricity and gas market. Commission staff working paper, SEC (2003) 448

⇒ Balancing: Another important issue for ensuring fair network access centres on the conditions associated with balancing. Balancing is carried out by the transmission system operator (TSO) who usually charges network users for the service of providing “top-up” or

disposing of “spill” energy. The conditions for balancing are important for new entrants since they often have a smaller portfolio of clients and the risk of imbalance is usually higher. In most Member States the price of balancing electricity is now established on the basis of market principles, with the methodology used approved by the regulator. In other cases the prices are subject to direct regulation. However, in Belgium and Luxembourg it would appear that the TSO controls balancing without any regulatory intervention or a market process and there is some evidence that this makes conditions for new entrants unfavourable.

- Security of supply. The introduction of competition in the electricity and gas markets must be arranged so that customers can rely on a close to continuous and reliable supply. This means that there must be sufficient production and transportation capacity to deal with the varying levels of demand during the year and in different conditions. For electricity, the security of supply position is usually monitored by the transmission system operators (TSO) in the Member States concerned as a consequence of their function in balancing supply and demand in the network. TSOs, in any case, need to be aware of trends in generation and demand in order to plan for appropriate investments in the network. Table A.4 provides data on the reserve generating capacity position for 2002. Normally Member States expect to maintain the level of “remaining capacity” above 5% of available capacity, taking into account the scope for imports.

Table A.4: Electricity security of supply

	Security of Supply Position 2002				Measures to Encourage Peak Capacity			
	amount of reserve generating capacity ³⁰	import capacity (% of peak consumption)	% p.a. increase in peak load	increase in capacity by 2004 (GW)	Market based	Incentives e.g. capacity payments	Obligation on TSO or supplier	Tender by Regulator or TSO
Austria	34%	45%	+2.1%	0.4	x			
Belgium	2%	31%	+2.1%	0.2			x	
Denmark					x			
Finland					unknown			
France	16%	19%	+1.9%	0.4	x			
Germany	5%	15%	+0.5%	0.8	x			
Greece	7%	13%	+3.2%	1.2				(x)
Italy	9%	12%	+3.7%	5.7		(x)		
Ireland	-2%	6%	+3.0%	0.8		x		(x)
Luxembourg	-	100%	+2.8%	0.0	n.a.			
Netherlands	7%	28%	+3.0%	0.7			x	
Portugal	13%	13%	+4.0%	0.5		x		
Spain	16%	7%	+3.1%	4.6		x		
Sweden							x	
UK	12%	3%	+1.0%	5.0	x			
Nordel	1%	5%	+0.8%	6.0				

Source: Second benchmarking report on the implementation of the internal electricity and gas market. Commission staff working paper, SEC (2003) 448

- Environmental objectives. The low capital costs of gas-fired generation and its relative efficiency in fuel use is leading to its widespread adoption throughout the EU. Similarly, competition may also lead to the more rapid retirement of older and less environmentally sound capacity. This has happened in particular in the UK, which reduced emissions considerably

during the 1990s. However, the introduction of competition is also likely to lead to lower energy prices than would otherwise be the case. This is because competition will provide incentives for companies to reduce costs, for example, by closing inefficient plant. This provides a challenge in environmental terms since lower prices in themselves may encourage greater consumption and also reduce the viability of renewable energy, particularly if the external cost of the use of fossil fuels is not recognised. Since Member States have commitments to meet relating to the reduction of greenhouse gas and other emissions, it is important to ensure that market opening is made compatible with these. Table A.5 shows efforts of Member States to manage demand and encourage renewable generation.

Table A.5: Environmental policy framework

	VAT rate	energy tax	main RES support mechanism	Net addition to generation 1998-2001 (MW)			
				net new coal/oil	net new gas	net new RES/CHP	other
Austria	20	**	fixed feed in tariff	no information			
Belgium	21	*	quota system (green certs.)	-225	-225	+433	-
Denmark	25	***	quota system (green certs)	-803	+317	-	+32
Finland	22	*	investment subsidies	+270	+160	+307	+220
France	19.6/5.5	*	quota system (tender)	no information			
Germany	16	**	fixed feed in tariff	-166	-101	+3150	+1251
Greece	8	none	fixed feed in tariff plus subsidies	-80	+492	-	-
Ireland	12.5	none	quota system (tender)	0	+310	+1074	+84
Italy	20/10	**	quota system	-	+4880	+1167	-
Lux	6	*	fixed feed in tariff	no information			
Neth	19	***	quota system (green certs)	-	+227	+511	-
Portugal	5	none	fixed feed in tariff	-50	+660	-	-
Spain	16	*	fixed feed in tariff	+341	-	+5942	+1057
Sweden	25	**	quota system (green certs)	-2500	-	+7	-600
UK	17.5/5	*	quota system (tender)	-5228	+5734	+109	-257
Total				-8400	+12500	+12700	+1800

Source: Second benchmarking report on the implementation of the internal electricity and gas market. Commission staff working paper, SEC (2003) 448

The table demonstrates that all Member States have some kind of programme to support renewables and the effectiveness of such policies can be gauged by an examination of the fuel mix of net new capacity added during the years 1998-2001. This shows that remarkable progress is being made with regard to renewables, which comprise of nearly 50% of new capacity being added in Europe. The most important contributors to the increase in renewable energy sources in the period concerned are Germany and Spain. It should also be underlined that many Member States have an active fiscal policy for energy with the aim of increasing the use of renewable energy and reducing consumption. The main leaders in this area are Denmark and the Netherlands. However on this issue of energy taxation it is important to remember that gas and electricity cannot be considered in isolation. Coal and oil are also carbon-intensive fuels and need to be included in a comprehensive energy taxation system. The Council restarted discussions on the Commission's proposal for a Directive to restructure the taxation of energy [COM (1997) 30] and the adoption of these proposals is also encouraged.

To conclude, table A.6 shows the basic position by MS as at the end of February 2003, indicating the proportion of the market open to competition, the relevant thresholds and information on the regulation of the market and unbundling.

Table A.6: Electricity internal market situation in the EU

	Electricity					
	Market opening	size of open market Twh	eligibility threshold	100% in/by	Unbundling transmission	Network access
Austria	100%	52	-	2001	Legal	Reg.
Belgium ⁷	52%	40	1/10Gwh	2003/7	Legal	Reg.
Denmark	<u>100%</u>	32	-	2003	Legal	Reg.
Finland	100%	75	-	1997	Ownership	Reg.
France	<u>37%</u>	131	<u>7 Gwh</u>	<u>2007</u>	Management	Reg.
Germany	100%	483	-	1999	Legal ⁹	Neg.
Greece	34%	15	1kV	<u>2007</u>	Legal\Mgmt	Reg.
Ireland	<u>56%</u>	8	<u>0.1 Gwh</u>	2005	Legal\Mgmt	Reg.
Italy	<u>70%</u>	191	<u>0.1 Gwh</u>	<u>2007</u>	Own\Legal.	Reg.
Luxembourg	57%	3	20 gwh	<u>2007</u>	Management	Reg.
Netherlands	63%	62	3*80 A	2003	Ownership	Reg.
Portugal	45%	17	1kV	<u>2004</u>	Legal	Reg.
Spain	<u>100%</u>	188	-	2003	Ownership	Reg.
Sweden	100%	129	-	1998	Ownership	Reg.
UK	100% ¹¹	330	-	1998	Ownership	Reg.

Source: Second benchmarking report on the implementation of the internal electricity and gas market. Commission staff working paper, SEC (2003) 448.

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¹ By Francis Armand (ADEME), Gema San Bruno (ESHA), Maria Laguna (ESHA), and Celso Penche (ESHA)

² A part of the information presented in this chapter is taken from the French guidebook “Guide pour le montage de projets de petite hydroélectricité” ADEME – Géokos mai 2003.

³ ESHA - Presentation by Georges Babalis at Hidroenergia 97

⁴ See also TNSHP – Environmental group – Reserved flow – Short critical review of the methods of calculation at [Hwww.esha.be](http://www.esha.be)

⁵ A part of the following examples have been supplied by countries working in the European contract “SPLASH” (Spatial plans and Local Arrangement for Small Hydro): Ireland, Greece, and Portugal. Let them be thanked.

⁶ A part of the information presented in this chapter is taken from the French guidebook “Guide pour le montage de projets de petite hydroélectricité” ADEME – Géokos mai 2003.

⁷ Commission staff working paper, “Second benchmarking report on the implementation of the internal electricity and gas market”. SEC(2003) 448.

GLOSSARY

Alternating current (AC):

Electric current that reverses its polarity periodically (in contrast to direct current). In Europe the standard cycle frequency is 50 Hz, in N. and S. America 60 Hz.

Anadromous fish:

Fish (e.g. salmon), which ascend rivers from the sea at certain seasons to spawn.

Average Daily Flow:

The average daily quantity of water passing a specified gauging station.

Base flow:

That part of the discharge of a river contributed by groundwater flowing slowly through the soil and emerging into the river through the banks and bed.

BFI baseflow index:

The proportion of run-off that baseflow contributes.

Butterfly Valve:

A disc type water control valve, wholly enclosed in a circular pipe that may be opened and closed by an external lever. Often operated by a hydraulic system.

Capacitor:

A dielectric device, which momentarily absorbs and stores electric energy.

Catchment Area:

The whole of the land and water surface area contributing to the discharge at a particular point on a watercourse.

Cavitation:

A hydraulic phenomenon whereby liquid gasifies at low pressure and the vapour bubbles form and collapse virtually instantaneously causing hydraulic shock to the containing structure. This can lead to severe physical damage in some cases.

Compensation flow:

The minimum flow legally required to be released to the watercourse below an intake, dam or weir, to ensure adequate flow downstream for environmental, abstraction or fisheries purposes.

Demand (Electric):

The instantaneous requirement for power on an electric system (kW or MW). Demand Charge that portion of the charge for electric supply based upon the customer's demand characteristics.

Direct Current (DC):

Electricity that flows continuously in one direction sd contrasted with alternating current.

Draft tube:

A tube full of water extending from below the turbine to below the minimum water tailrace level.

Energy:

Work, measured in Newton metres or Joules. The electrical energy term generally used is kilowatt-hours (kWh) and represents power (kilowatts) operating for some period of time (hours)
 $1 \text{ kWh} = 3.6 \times 10^3 \text{ Joules}$.

Evapotranspiration:

The combined effect of evaporation and transpiration.

FDC:

Flow duration curve: a graph of discharges against v. the percentage of time (of the period of record) during which particular magnitudes of discharge were equalled or exceeded.

Fish Ladder:

A structure consisting e.g. of a series of overflow weirs which are arranged in steps that rise about 30 cm in 3 50 4 m horizontally, and serve as a means for allowing migrant fish to travel upstream past a dam or weir.

Flashboards:

One or more tier of boards supported by vertical pins embedded in sockets in the spillway crest.

Flow duration curve:

See FDC

Forebay:

A pond or basin of enlarged water. Surface and depth, usually at the end of a canal or leat, from whence a penstock leads to a powerhouse.

Freeboard:

In a canal, the height of the bank above the water level.

Gabions:

Large, usually rectangular, boxes of metal mesh filled with stones or broken rock.

Gate Valve:

A vertical gate type water control valve, requiring more space than an equivalent diameter butterfly valve, which can be opened either mechanically or hydraulically.

Geotextiles:

Synthetic materials (e.g. polypropylene, nylon) woven into rolls or mats which are laid as permanent but permeable foundation blankets under stone, rock or other revetment materials.

Governor:

A controlling device that adjust the flow of water through the turbine following the output signal of a certain sensor (turbine speed, intake water level etc.).

Gravitational constant g:

Acceleration due to gravity, approximately 9.81 m/s².

HDPE:

High-density polyethylene

Head, gross:

The difference in level between the water surfaces at intake and tailrace of a hydroelectric system

Head, net:

The head available for power generation at the turbine, incorporating all head losses in screens, intakes, pipes, valves, draft tube and tailrace.

Headpond:

See “forebay”.

Hertz (Hz):

Cycles per second, as applied to ac generation.

Hydraulic gradient:

The hydraulic pressure profile along a pipe or conduit, which is flowing full.

Infiltration:

The process whereby rainfall penetrates through the land surface to form soil moisture or groundwater.

Installed capacity:

The total maximum capacity of the generating units in a hydropower plant.

Isovels:

Lines of equal velocity drawn on cross-sections of watercourses.

Leat:

An open channel that conveys water at a shallow gradient from a river intake to point where sufficient head has been gained for a turbine to be installed. (Also sometimes called GOIT or CONTOUR CANAL).

Load (Electrical):

The power capacity supplied by a particular plant on an electric system.

Load factor:

Is defined as the ratio annual energy output kWh/max power output x 8760 hours

Outage:

The period in which a generating unit, transmission line, or other facility, is out of service.

Output:

The amount of power (or energy, depending on definition) delivered by a piece of equipment, station or system.

(In) Parallel:

The term used to signify that a generating unit is working in connection with the mains supply, and hence operating synchronously at the same frequency.

Overspeed:

The speed of the runner when, under design conditions, all external loads are removed

P.E.:

Polyethylene

Peak Load:

The electric load at the time of maximum demand.

Peaking Plant:

A power plant, which generates principally during the maximum demand periods of an electrical supply network.

Penstock:

A pipe (usually of steel, concrete or cast iron and occasionally plastic) that conveys water under pressure from the forebay to the turbine.

Percolation:

The movement of water downwards through the soil particles to the phreatic surface (surface of saturation within the soil; also called the groundwater level).

Power:

The capacity to perform work. Measured in joules/sec or watts ($1\text{MW} = 1\text{ j/s}$). Electrical power is measured in kW.

Power factor:

The ratio of the amount of power, measured in kilowatts (kW) to the apparent power measured in kilovolt-amperes (kVA).

Rating curve:

The correlation between stage and discharge.

Reynolds Number:

A dimensionless parameter used in pipe friction calculations (interalia), and derived from pipe diameter, liquid velocity and kinematic viscosity.

Rip-rap:

Stone, broken rock or concrete block revetment materials placed randomly in layers as protection from erosion.

Runoff:

The rainfall, which actually does enter the stream as either surface or subsurface flow.

Run-of-river scheme:

Plants where water is used at a rate no greater than that with which it “runs” down the river.

SOIL:

A parameter of permeability

Stage (of a river):

The elevation of water surface

Supercritical flow:

Rapid flow who is unaffected by conditions downstream

Synchronous speed:

The rotational speed of the generator such that the frequency of the alternating current is precisely the same as that of the system being supplied.

Tailrace:

The discharge channel from a turbine before joining the main river channel.

Trashrack:

An structure made up of one or more panels, each generally fabricated of a series of evenly spaced parallel metal bars.

Utilisation Factor:

The ratio found by dividing the number of hours per year (or other unit time) that a plant is generating, by the number of hours in a year (or in the other unit time). (This is not the same as load factor).

Weighted average rainfall:

The average rainfall over an entire catchment that allows for the variation in rainfall between the wetter and drier areas.

Weir:

A low dam, which is designed to provide sufficient upstream depth for, a water intake while allowing water to pass over its crest.