

Refurbish low head small hydroelectric plants: guidelines and lessons learned

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1 Abstract

In the frame of SHAPES (Small Hydro Action for the Promotion of Efficient Solutions), a project coordinated by ESHA, funded by the EC and under completion in April 2010, one of the deliverables was the “Guide on how to refurbish a low head small hydroelectric plant”.

The guide, a 24 pages documents addressed to people with a basic knowledge of small hydroelectric plants, summarises the main actions to be taken using as a starting point the technical and operational factors which influence the Net Present Value of the investment, namely, the overall efficiency, net head, flow rate, hours of operation, investment, operating and maintenance costs.

The main streamline to face a low head refurbishment is outlined in the guide, underlining, by the other side, the main issues to be taken into account and mainly related to:

- management of large flow rates (civil works prevailing)
- attention to open channel hydraulic phenomena
- global optimisation approach rather than optimisation of the single component (namely the generating set)
- deep investigation of site constraints and boundary conditions to choose the optimised solution.

The full paper will present in more detail both the general approach and some case studies to exemplifies the approach described.

2 Foreword

The Guide on how to refurbish a low head small hydroelectric plant is addressed to people interested in the refurbishment of low head small hydroelectric plants and already having some basic knowledge of the main technical issues involved in the small hydro subject.

That’s why in the guide, in order to keep it of a reasonable size and as much effective as possible, the aforesaid basic knowledge is taken for granted.

Furthermore, the guide will be focused on its three cross-specificities: refurbishment, low head and small hydroelectric plants.

According to this approach, addressed only to the specificities of the subject, the guide doesn’t enter in any detail the usual activities connected with the implementation of a small hydroelectric plant (collection and interpretation of hydrological data, estimation of gross and net head, economic evaluations etc.), but it refers to those activities only when relevant to the subject and advisable to face them in a particular way.

3 Basic Technical-economic presuppositions

Refurbish a low head plant needs money, and usually a lot of money, as small hydro investments are capital intensive. Furthermore, low heads plants highly suffer of scale effects, mainly because, if compared to a high head plant with the same output, they have a greater incidence of civil works cost.

In any case, when you have to refurbish the plant you must rank different project alternatives, included the zero alternative, that is no refurbishment at all.

The best method for doing that is through the NPV (Net Present Value) method:

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

Where

- | | |
|---|---|
| i = lifetime period as year, quarter, month, etc | I_i = investment in period i [CU] |
| R_i = revenues in period i [CU] | O_i = operating costs in period i [CU] |
| M_i = maintenance costs in period i [Currency unit] | V_r = residual value of the investment [CU] |
| E_v = environmental added value of the plant [CU] | r = periodic discount rate [%] |
| n = number of lifetime periods | |

4 Fields of action

For the scope of the guide it’s important to make more explicit in the NPV formula the term related to revenues R_i

$$R_i = P_i \cdot E_i = Pr_i \cdot \eta_i \cdot \gamma \cdot H_i \cdot Q_i \cdot T_i$$

Where:

P_i = price of the energy produced in period i [CU/kWh] E_i = energy produced in period i [kWh/unit of period]
 η_i = overall efficiency of the plant in period i [%] γ = unit weight of water [kN/m³]
 H_i = net head in period i [m] Q_i = flow rate in period i [m³/s]
 T_i = hours of operation in period i [h]

The said formula, coupled with the NPV formula, leads to:

$$NPV = \sum_{i=1}^n \frac{[P_i \cdot \eta_i \cdot \gamma \cdot H_i \cdot Q_i \cdot T_i - (I_i + O_i + M_i)]}{(1+r)^i} + V_r + E_v$$

Each factor of this formula represents a field of action in the context of a refurbishment, exception made, in general, for the financial parameter r and the energy price P_i .

The environmental issue needs a short comment. Environmental added value can't be reduced to a purely monetary value. In this context there's only the need of taking into account, in the following considerations, the fact that, during the refurbishment, different alternatives can have different environmental consequences both in terms of purely monetary costs and even of environmental benefits.

5 Actions on Q

5.1 By reducing waterways roughness

The easiest and cheapest way to increase flow rate in a low head plant is by reducing the roughness of the waterways, namely headrace and tailrace channels, the weir crest level being equal: smoother surfaces of walls and sills allow for smaller friction losses and, water level being equal, for a higher flow rate conveyed.

The ways to get a smaller roughness depend on the structure of the waterways: in earthen channels (not very usual, especially for headrace channels, but more frequent for tailraces) the possible actions are few and mainly linked with keeping the slopes clean from weeds. In artificial channels the task is easier: on the market many different types of special products (one or two components waterproof mortars incorporating admixtures, fibres and comprising liquid polymer and special cements) are available for this purpose; it must be noted that those products must be applied very carefully taking into account the conditions of the surface where the product is applied to, the weather conditions and so on, because they are very sensitive to all of them, and in case of improper application the results can be a real disaster, even worsening the situation before application.

Anyway don't trust too much those kinds of actions in the evaluation of the final plant performances in terms of flow rate conveyed, because roughness is bound to increase in time due notably to wearing of the coatings, weeds and algae growing.

5.2 By increasing the area of the cross section of the waterways [e.g. from earth-trapezoidal to concrete-rectangular]

Increasing the area of the cross section of the headrace and/or tailrace channel, if it's viable both economically and from the spatial constraints point of view, is for sure a better solution than acting on roughness only.

A typical solution is to change from earth-trapezoidal or masonry-trapezoidal to concrete-rectangular cross section. Many low head hydropower channels were built with a trapezoidal section. There's a technical-economic reason for that: this kind of section, in duly proportions, has the minimum wetted perimeter and volume of excavation, so that it is the section with the best hydraulic performances and the minimum construction cost.

Trapezoidal sections, both natural and masonry-coated have many problems: natural sections are subject to sliding of slopes, weeds growing, stability problems; masonry-coated are subject to cracks, water leakages, local coating heavy deterioration, all problems due to the interaction with the substrate and to the fact that the coating isn't of the self-bearing type.

A self-bearing rectangular section made by reinforced concrete can solve all the above mentioned problems and at the same time can remarkably increase the flow rate conveyed by the channel being the levels equal.

The main disadvantage of this solution is the high cost of investment.

The following important aspects have to be taken into account:

- joints design and realisation;
- drainage of side walls and bottom sill, to be evaluated case by case;
- constraints coming from local boundary conditions;
- access and realisation problems.

5.3 By increasing the flow rate by negotiating a new water right with a higher rated discharge (*Errore. L'origine riferimento non è stata trovata.*)

For some cases, the rated discharge defined in the water right can be negotiated and increased. Indeed, most of the old sites were dimensioned for the output necessary for the corresponding mills (saw mills, flour ones, ...).

It happens when the water stream hydrology and environmental impact studies demonstrate that the discharge reduction in the river bed is acceptable in front of the new positive impacts, resulting from the maintenance of the patrimony, the fish migration improvement and the green electricity production increase.

Of course, this implies administrative procedures that are not guaranteed and not for free, but they are worth achieving in front of the added annual production.

6 Actions on H

6.1 By increasing the weir elevation (*Errore. L'origine riferimento non è stata trovata.* and *Errore. L'origine riferimento non è stata trovata.*)

This action is mentioned even though it's not very usual. Many different conditions must be met to increase the weir elevation and, consequently, the gross head of the plant:

- global stability of the raised weir must be guaranteed with suitable safety factors. If it's not the case, the cost for getting the said safety factors must be duly compensated by higher energy production due to this higher gross head;
- higher water depth and greater length of the backwater area must be consistent to the environmental status of the river and to the water rights of the water users upstream (the increase of this gross head could decrease the one of a possible power plant located upstream);
- a higher water level determined by a higher weir implies a higher depth in the headrace channel, if any, which can lead to problems of side stability and freeboard. Thus they have to be closely examined in a way similar to the weir raising.

6.2 By restoring the initial gross head

In old small hydro low head plants, it's not unusual that the gross head is decreased because of material sedimentation downstream of the powerhouse or in the tailrace channel.

Restoration of the gross head can be achieved by dredging the tailrace channel or the river.

The benefit of this action must be carefully evaluated because some cons are anyway connected to it:

- dredging is an expensive activity;
- the material dredged from the river must be disposed: if it has an economic value (gravel, sand) as a component for concrete, the disposal is rather easy and it's possible to have some revenue reselling the material (if allowed by the national legislation); if it hasn't, the disposal itself is expensive: in medium or large river tailrace dredging can imply handling thousands of cubic meters of material and to find a final destination for is not an easy task;
- river dredging can have a negative environmental impact on the riverine ecosystem;
- sediment dynamics can be such that after a few years the problem must be faced again.

6.3 By replacing old screens equipped by rectangular bars with screens with hydrodynamic profile

Old small hydro low head plants are equipped with screens made by steel rectangular bars. The screens are usually located at the forebay upstream of the turbine or at the intake or both. Screens are sometimes equipped with trash rack cleaning machines (TRCMs). In very small plants and in some very old and never modernised ones the screens are manually cleaned.

When a plant is planned to be refurbished, an interesting option regarding screens can be the replacement of conventional steel rectangular bars with hydro-dynamically profiled screens. These screens can greatly reduce head losses and thus increase the net head of the plant. The steel solution is more expensive if compared with the rectangular one (approx. +60 % including installation), but now GRP (glass reinforced plastics), a solution are less expensive and with a comparable reliability.

Hydrodynamic profiles allow for a reduction of the head losses up to one third of the correspondent rectangular bars and can be cleaned in an easier way. Sometimes it is necessary to undertake this action to compensate smaller distance between bars due to demands of fishery

7 Actions on η and T - Turbine and generator replacement

7.1 Foreword

Actions on η , global efficiency, are related to actions on turbine-generator (TG) unit. As usually the main reason for refurbishment is the dramatic decrease of the TG efficiency and number and duration increase of unit trips due to the unit age, an important effect connected to the replacement is the operation time increase. It must be said that in many situations this side effect is even more important than the efficiency increase itself.

The most common and frequent way to refurbish a plant is to replace the turbine.

Thanks to technological progress and R&D effort in the low head turbines design, many different options are available now with respect to the past to exploit the same head and flow rate.

That's why the final choice of the unit must be the result of an optimisation process which must take into account the boundary conditions and the local constraints into the decision process.

7.2 What's worth replacing?

Even the simplest possible choice in a unit replacement, that is to replace the old unit(s) with a new one(s) perfectly the same, is not so obvious. Yes, because, from one side, if you decide to replace even the parts in concrete you have higher costs, probably higher efficiencies, less constraints and some risks; by the other side, if you keep the

embedded parts as they are (typically the draft tube and, if any, the spiral case), you have a strong constraint on the new unit construction.

In fact you don't exactly know which is the geometry of the coupling between embedded and not embedded parts (you can only partially trust in old construction drawings): you must wait for dismantling the old unit, check the real geometry, adjust very precisely from the mechanical point of view the coupling surfaces; all this process can take a lot of time and prolong the unit outage with the consequent loss of production.

That's why in many cases even the embedded parts are worth replacing, independently from any consideration about the efficiency improvement of the units.

But the replacement of the embedded parts makes further problems arise, mainly the replacement of the draft tube of both Kaplan and Francis open flume units, such as:

1. problems due to the necessity of works below the tailrace water level, strongly constrained by the interaction with the existing structures;
2. problems due to the fluid-dynamics design of the draft tube.

Certainly the most critical is the first one.

7.2.1 Works below the tailrace water level (Errore. L'origine riferimento non è stata trovata.)

Only in a few cases of an open flume Francis turbines replaced with the same type of unit you may not face this problem. Actually, as open flume Francis turbines were usually built and installed before the cavitation effects were completely known, many draft tubes of those units are installed well above the tailrace water level; but even though for reasons of global optimisation the choice of replacing a Francis open flume with a similar unit is taken, you must necessarily lower the level of the runner and consequently even the level of the draft tube with the consequent risk of works below the tailrace level.

This kind of works has peculiar features:

1. they are expensive;
2. they are subject to a high degree of uncertainty and consequently to a high risk of unexpected increase of the refurbishment costs.

In principle the actions to be taken when there's the need for works below the tailwater level are well known, and many different technologies are available.

The main need is to keep away water from the working area. Apparently it's an easy task: it's enough to install at a suitable low level some suitable pumps.

Actually, the satisfaction of this simple need encounters many difficulties:

1. pumps may interfere with the progress of the works: typically, if you have to replace the old draft tube, once installed the new draft tube, you must embed it into the concrete. Pumps, located at the lowest possible level, and anyway lower than the lowest part of the draft tube, should be removed before concrete casting; but if you remove the pumps, the working area is inundated by water and you should cast concrete under water with further difficulties and uncertain final results.
2. when you pump water coming from the water table, you can have a high risk of washing out even the finest particles of the terrain around the powerhouse: this situation is very dangerous because of the risk that part of the powerhouse foundations may collapse.

7.2.2 Fluid-dynamics design of the draft tube

It could seem strange that the fluid-dynamics design of the draft tube is a critical issue: with respect to the past excellent CFD (Computational Fluid Dynamics) systems are available for the flow simulation in draft tubes. The use of those tools is widely diffused in the design of small hydro units, in order to cut laboratory full model costs, usually not affordable for small hydro plants operators.

Nevertheless, wrong design of new draft tubes is frequent.

It must be said that the draft tube design has been quite improved over the years: recently designed draft tubes have a shape very different from the past with undoubted higher efficiency. Nevertheless many partially unknown factors can still affect the final result of the draft tube replacement, especially at particular partial load of the units. A large bibliography is available on this topic.

7.2.3 Embedded parts

New units have generally shapes and dimensions different from old ones, so that when you replace an old unit you must evaluate also the possibility of removing embedded parts of the unit, typically stay vanes, discharge rings, stay rings, spiral cases.

Any interaction with civil works is potentially a source of risk, especially in case of old buildings whose actual conditions are very often not completely known.

Contingencies must be expected, affecting both time and costs of refurbishment.

The simplest way to overcome this problems is a radical action on the civil works, that is actually realising a completely new civil structure avoiding to keep some parts of them in the easy illusion of reducing costs.

Moreover, keeping old embedded parts represents a strong constraint to an optimal hydraulic design of the new unit and it usually results in lower efficiency.

7.3 *How many units?*

In the past, very old plants were equipped with more than one unit in order to have the best possible exploitation of the available water resources and the best efficiencies of the units. Indeed, all Francis turbines, even open flume ones don't work well at partial loads, so that to exploit at its best the water available more than one unit was installed.

This is still a typical choice for large hydro plants, even though in that case also mechanical, transport and erection problems are at the basis of the multiple-units choice.

It must also be noted that old plants used to have many units even for another important historical reason: many plants were built to supply mechanical force to drive mills, saw mills, textile workshops, so it was important to be able to operate the plants at partial load to meet the instantaneous energy demand of the workshops.

Coming back to small hydro, nowadays, in case of refurbishment, one unit only (or less units than in the past) is preferred for economic (in general one big unit is cheaper than two units with halved output) and operation (automation, control and management of more units is more complex) reasons.

In any case, as rather usual in refurbishment of low head plants, it's difficult to state a general rule. Once again the general optimisation of the project must be kept in mind: the installation of one new unit instead of three old ones can be cheaper from the electro-mechanical side, but it can be unfeasible or very expensive or subject to higher contingencies due to strong actions needed on civil works.

7.4 *Replacement of an old TG unit with a new one of the same type*

7.4.1 **Francis open flume turbines (FOF)**

The reason for replacing an old unit with a new one is usually the quick efficiency decrease or the more and more frequent plant outages due to the unit unreliability. In many cases it deals not only with the runner itself but also with auxiliary components, such as lubrication and cooling systems, bearings, and over-temperatures.

Very old low head units are Francis open flume turbines directly coupled to generators.

After the invention of Kaplan turbines this kind of units has been rapidly abandoned as possible technical solutions to exploit low heads, so that also the hydraulic research and development on these units haven't been carried out any more.

Anyway, when old FOF must be replaced, the possibility of replacing it (or, more frequently, them, because, as all Francis turbines, even open flume turbines don't work well at partial loads, so that to exploit at its best the available water more than one unit was installed) must be taken into due consideration.

For sure this choice isn't in the direction of the innovation, but, as we said many times, the scope of the refurbishment is the overall optimisation of the plant and not of one part only.

The replacement of an old open flume Francis turbine with a new one particularly makes sense in situations with strong transport and erection constraints. As the modern alternative to FOF is a Kaplan turbine, the complete different size, configuration and weight of a Kaplan turbine with respect to a FOF must be evaluated with reference to site management.

Pros and cons can be summarised as follow:

	<i>Erection</i>	<i>Interaction with civil works</i>	<i>Efficiency</i>	<i>Number of units</i>
FOF	☹	☹	☹	☹
Kaplan	☹	☹	☺	☺

7.4.2 **Kaplan turbines**

Replacing an old Kaplan turbine with a new one is apparently the easiest possible task.

Actually, even though the plant parameters are the same (rated head and flow, FDC, etc.), it's rather usual that the new unit can be different from the old one in many aspects, such as:

- rated speed (higher speeds are now frequent)
- blades number (connected to speed, being Q and H the same)
- runner diameter
- draft tube shape (modern draft tube design is rather different from old one)
- runner centreline elevation (actual knowledge of cavitation phenomena often entails lower elevations)

All those aspects require some adaptation of the new unit to the existing both mechanical and civil structures.

During the preliminary design stage, the consequences of any mechanical and hydraulic optimisation must be carefully examined by means of a deep cost/benefits/risks analysis. Sometimes what is simple or cheap in the workshop construction phase can have negative impacts on the works on site because of higher contingencies or of longer refurbishing times.

Keeping inner and outer rings is a typical example. It's obviously cheaper to keep these parts because their construction is expensive and takes time. By the other side you must machine on site the existing rings and you can

encounter two possible risks: such a bad mechanical condition that the replacement is needed (more money and more plant outage) or prolonged site machining due the remarkable lack of planarity.

7.5 *Replacement of an old TG unit with a new one of a different type*

When the decision of replacing an old TG unit is taken, at a low head plant many options, different from the simple replacement with a similar one, are now available. Basically even the new available options are of the reaction type. The option of replacing an old turbine with an action or an Archimedean screw turbine can be considered only in limited cases. But in the great family of the reaction turbines there are many different solutions that have some peculiarities from the general configuration point of view.

The final choice depends, as mentioned above, from the global optimisation of the refurbishment and not only of the unit replacement itself.

All the possible solutions have pros and cons.

7.5.1 **Replace an old FOF turbine with a Vertical Bulb Turbines (VBT) in the same pit**

In order to reduce as much as possible the works on existing structures, a viable solution is the installation of a Vertical Bulb Turbine in the same pit where the old FOF was.

In this case the dimensions of the bulb are the main problem. A conventional bulb usually has a large diameter and its fitting in the available space must be duly checked to be sure that the unit hydraulic behaviour is satisfactory.

A new opportunity to use this solution is given by the installation of a Permanent Magnet Generator (PMG). If compared to a conventional one a PMG is more compact and has comparable efficiencies at any load. That's why in recent years, sometimes coupled to Variable Speed Operation (VSO) generators, PMG have known a growing interest and application in the low heads field.

8 **Actions on T**

8.1 *By improving sediment management*

The operation of many low head plants is negatively affected by sediments transported by water and deposited in key parts of the plants. The main consequences are:

- Reduction of the capability of conveying water to the plant (sedimentation at intake)
- Reduction of cross section in the waterways (sedimentation in headrace and forebays)
- Reduction of head (sedimentation downstream of the powerhouse)
- Plant outages for sediment removal

In many cases the reasons for excessive deposition lies in original sins of the plants, namely:

- Incorrect position of the intake in the river (typically in the inner side of a bend instead of on the outer one)
- Insufficient dimensions of the flushing devices at intake or at forebays
- Underestimation of the quantity of sediments transported or incorrect evaluation of their prevailing size
- Insufficient or incorrect design of the desilting basins (if any)
- General layout of the intake and waterways favouring deposition.

So, the actions taken during the plant refurbishment can positively affect the sediment management. The field of improvement is directly connected to the cause:

- Modification of the shape of the river at the intake reducing the inner curvature (very difficult, in general, both from both technical and administrative point of view, with high environmental impact and probably only temporary results unless combined with other actions)
- Improvement of the flushing devices at intakes and forebays, e.g. lowering the sill level of desilting gates, enlarging their width or both
- Installation of bottom deflectors or of other devices capable of locally increasing flow velocity during flushing.

8.2 *By improving trash management*

It is never enough underlined that a good trash management is vital for the operation of a low head plant.

Some old and small low head plants have no trash rack cleaning machines (TRCM) and debris is removed manually from screens.

This kind of operation has rather evidently high operation costs and is not efficient (hydro plants work day and night and debris are conveyed 24 hours a day). If a TRCM is not present at the plant, in case of refurbishment, one essential action is to set a new one. Even the replacement of an old or inefficient TRCM is an option.

Once stated the necessity of setting a new TRCM (and of the relevant screen), the choice of the typology is also essential.

There's no general rule for that, but some criteria can be suggested:

- Debris load: for heavy loads (branches, logs) a hydraulic driven TRCM is usually preferred. If mainly light loads (leaves, small wood) are expected, even a chain or rope rotating TRCM can be a viable (and usually cheaper) solution
- Accessibility of the site to dispose of the debris removed from the water
- Possibility of remove debris from screens avoiding the abstraction from water and the relevant disposal (with the cost connected). There are TRCM solutions with screens equipped by horizontal bars, which remove debris from

the screen and move them on one side. By opening a gate (a flap gate or a sliding gate equipped with a flap gate on the top) the debris are flushed downstream without being removed from water. These solutions have also the intrinsic environmental benefit of keeping in the water the organic fraction of debris, which plays an important role for riverine ecosystems.

8.3 *By improving floating debris management (Errore. L'origine riferimento non è stata trovata.)*

One of the most frequent causes of plant outage is the inefficiency of systems for managing floating bodies.

Especially during high or medium water periods, (typically in spring or early summer after snowmelt time), rivers convey a large amount of floating bodies, which tend to enter the plant waterways and to clog screens at intakes and forebays.

These are simple plastic buoyant bodies of given length (approx. 3-4 m each), properly shaped and duly connected, usually by galvanized steel connectors, and anchored to the banks with a concrete foundation designed to withstand the thrust of the floating material stopped by the booms themselves.

They should be located at the intake while considering the necessity of flushing downstream the floating material. This is a key issue of the whole system. In case of fixed weirs the booms position and shape when floating debris are right against them, must be carefully designed, in order to be sure that flow over the crest of the weir, in case of incoming discharges higher than the plant rated discharge of the plant, is enough to flush downstream the floating bodies .

In case of moveable weirs, you have different options:

- to set a flap gate as near as possible to the booms. By opening, even partially, the gate you flush downstream the debris. In order to favour debris removal from booms, sometimes the flow rate diverted by the plant is reduced (and the approach velocity to the booms, too) and at the same time the gate is lowered;
- to check whether existing gates of other types at the weir are able to flush floating debris. If sliding gates are installed, you can anyway flush floating debris, but the gates must be completely raised and operating in spillway mode: in orifice mode, in fact, floating debris can't be efficiently flushed. An alternative to that is given by a modification of existing sliding gates by the installation on top of them of a small flap gate.

A correct curvature of the booms under the thrusts of the floating bodies is essential for the efficient operation of the system.

8.4 *By improving weir operation safety (Errore. L'origine riferimento non è stata trovata.)*

When a weir of an old low head small plant is equipped with moveable gates, very often these gates have small width with many intermediate piers. This kind of weir layout makes it vulnerable to clogging during floods because the large material transported (trunks, branches, etc.) can obstruct the waterways.

The reason for many small gates was essentially an economic one: gates with wide span required special construction, sometimes not compatible with the economics of a small plant. By the other part, many small gates can cause more frequent outages and an operation costs increase due to the necessity of removing material just against the gates, a complicated activity.

That's why, in the refurbishment framework, it makes sense to take into consideration, if the preliminary assessment of the criticalities showed it as a weak point, to modify the weir layout by replacing many old sliding gates with few flap gates or sector gates or inflatable rubber dams, eventually protected by steel panels.

Each one of the aforesaid options has pros and cons and their own more specific application, even though all of them are in some way equivalent.

The following table summarizes the main features:

	<i>Suitability for water level regulation</i>	<i>Risk of damage during floods</i>	<i>Cost</i>	<i>Construction</i>	<i>Erection</i>	<i>Civil works</i>
Flap gates	☺	☺	☹	☹	☹	☹
Sector gates	☺	☺	☹	☹	☹	☹
Rubber dams	☹	☹	☺	☺	☺	☺
Rubber dams with steel panels	☺	☺	☺	☺	☺	☺

It must be kept in mind that, in any case, a fundamental role is played by temporary works in the river for replacing the gates. These works must be properly designed to withstand the project flood and to protect working areas from water. In some situations, on the contrary, you must design temporary dykes in order to be overtopped by a predefined flood to avoid damages at the structures located upstream (villages, various activities, etc.) but to protect from ordinary flow rates the working site. It's quite essential to plan carefully all the activities in the river, rather obviously choosing the river low flow period, with the lowest risk of flood.

Another important issue in the choice among different alternatives is related to the interaction with civil works and primarily with foundations.

Some types of gates (flap and sector ones, mainly) transfer hydraulic loads in concentrated points to foundations so that special foundations (piles, sheet piles) can be necessary to withstand those loads. Special foundations are expensive, require time and skill to be built, especially in the difficult conditions typical of works in rivers, and are

subject to frequent contingencies, so that a deep analysis of the opportunity of the alternative requiring those works must be carried out.

8.5 *By setting or improving plant automation*

In the frame of a refurbishment, it's quite usual to implement the automation of the plant or to modernise and update the existing one. About this topic there's nothing really specific to low head plants. In any case, even considering the rapidly decreasing costs of hardware and software, it's advisable to acquire as many data from the field as possible in order to have a clear picture of the situation of the plant and of the evolution of the main plant parameters in the time. Particular attention should be paid to:

- Units vibration
 - Bearings temperature
 - HPU (hydraulic power unit) pressures and temperatures.
- Generator and transformer temperatures
Upstream and downstream water levels

9 **Environmental added value**

The refurbishment of a low head plant can be a good opportunity (sometimes an obligation) to increase the environmental added value of the plant by suitable actions aimed at improving the plant environmental sustainability.

It must be said that the environmental performance improvement of an existing low head plant is a difficult task because of the many constraints coming from acting on existing hydraulic works, so that, as for any other action during refurbishment, an optimised solution rather than an optimum solution can be achieved in the most favourable situations.

Possible actions related to this topic are:

- fish passages: many old low head small hydro plants aren't equipped with fish passages or are equipped with inefficient ones. Within a refurbishment the realisation of a fish passage can be a good opportunity to improve the plant environmental performance. Unfortunately it's not an easy task. The main risk is the construction of an expensive passage with low efficiency because of the general layout of the weir and of the intake. Typically it's impossible to put the passage in a suitable position to properly attract fish to the passage itself in both migration directions.
- Architectural and visual impacts: refurbishment can include also actions on buildings, mainly the powerhouse, connected with the hydroelectric units replacement, but also on the weir or on the intake. Some design choices can be taken keeping in mind the reduction of the visual impact of the plant, e.g. installing new gates at weir with lower visual impact (flap gates, or rubber dams with steel protection panels which don't require intermediate piers or footbridges).
- Fish friendly turbines: since many years research on fish-friendly turbines is ongoing all over the world, mainly addressed to large hydro low head turbines. Small hydro application, exception made for very low head (with low speed, rather large diameters and gaps) are undoubtedly more difficult, especially in case of refurbishment, where the constraints coming from existing structures don't generally allow for installation of units typology with better environmental behaviour than conventional ones (e.g. Archimedean screws).
- Installation of screens with reduced space between bars: the reduction of space between bars implies a lower risk of fish entering the plant and the turbines, but also higher head losses, so that in order to keep them at a reasonable level this action can be connected preferably to the installation of hydrodynamically-profiled bars.
- Fish dissuasion or attraction systems: this action, in general rather expensive both from the investment and operation point of view, can be envisaged whenever, because of the plant layout, it's difficult to keep fish away from the intake or to attract it to the passage.

10 **Flood management added value**

The rehabilitation of old sites often results in an improvement of the flood management. It can be noticed especially for destroyed weirs. Indeed for these sites, problems with the river banks can occur, that keep on increasing if nothing is done. Then the rehabilitation of the site infers new equipment and an opportunity to study the area as a whole, considering the electricity production and the flood management. Then, new valves can be integrated, that can be regulated with the water level variations. Then by-passes and basins can be created to better manage the high discharges. Moreover it can be here added that turbines are most of the time regulated to maintain a steady upstream level.

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