

Mini hydro plants exploiting ecological flow - ready to go!

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Introduction

Back in 2005 Studio Frosio gave the first presentation in a hydropower conference dealing with the potential exploitation of the reserved (ecological) flow for hydropower energy production. At that time, only a few, peculiar and near-experimental applications on both medium-high and low heads were implemented.

Nearly ten years later, thanks to new and more mature technologies available (mainly in the hydroelectric units field) and, no less important, to a clearer and more favourable authorisation and tariffs frame, dozens of plants which use the ecological flow are ready for implementation in Italy.

Most of these plants are low or very low head schemes, exploiting the reserved flow released at existing diversion weirs; In fact medium and high head applications - usually consisting in drilling a hole and inserting a penstock in a dam's wall - have been nearly abandoned, due to the complications in the authorisation (subject to the approval and rules of the national dam service) and realisation (difficult and expensive) process. Actually the main technological developments in the last decade are related to low head hydropower plants, as chapter 3 illustrates.

Furthermore an overview on the main reserved flow plants designed by STUDIO FROSIO is given in the following chapters, underlining the most critical design and operation issues as well.

In the end a brief outlook on the future perspectives of reserved flow exploitation in Italy is given, in the light of the ongoing technological development.

1. Overview

The following table summarises the main features of some of the most representative plants designed by STUDIO FROSIO in the last decade. As mentioned in the introduction, all of them are low head schemes, ranging from 2,15 to 5,20 m of head and from 1,80 of 56,10 m³/s of (usually constant) flow rate.

<i>Name of the plant</i>	<i>River</i>	<i>Maximum flow [m³/s]</i>	<i>Average flow [m³/s]</i>	<i>Gross head [m]</i>	<i>Installed capacity [kW]</i>	<i>Authorisation stage (as of August 2014)</i>
<i>Casnigo Scarico</i>	Serio	1,64	1,64	3,05	40	Under construction
<i>Casnigo</i>	Serio	1,58	1,58	5,20	70	Under construction
<i>Parre</i>	Serio	3,00	1,89	4,30	98	Under construction
<i>Prato Mele</i>	Serio	2,46	1,90	4,70	94	Under construction
<i>Fonderia</i>	Brembo	2,45	2,45	3,50	70	Under construction
<i>Esine</i>	Oglio	4,50	3,10	4,20	155	Final design stage
<i>Capriolo</i>	Oglio	10,00	4,13	5,90	480	Under construction
<i>Roggia Vetra</i>	Oglio	10,00	6,54	6,30	600	Final design stage
<i>Urago</i>	Oglio	12,00	10,21	3,50	350	Final design stage
<i>Carema</i>	Dora Baltea	24,00	16,48	4,00	770	Final design stage
<i>Chievo</i>	Adige	56,10	56,10	3,10	1.480	Operating

All those plants exploiting the reserved flow are located at the inlet of existing water diversions, usually done for hydropower purposes - sometimes combined with irrigation schemes; therefore the design problems connected with the optimisation of the joint operation of the two plants, the main one and the reserved flow one, must be considered as well.

1.1 Upstream water level regulation

Usually the “main” plant is operated by regulating the water level just upstream of the hydroelectric units, therefore the water level at the weir, where the reserved flow plant shall be constructed, varies with the flow rate diverted by the main plant, as well as with the flow rate of the water course.

As a reserved flow plant usually has a small power output, the analysis of its technical and economical feasibility must evaluate and compare the cost of installing gates - or replacing the existing ones - for regulating the upstream water level at the weir and of losing a certain fraction (up to some tens percent) of the available head due to water level fluctuations.

1.2 Downstream water level variations

The water level upstream of the weir and of the reserved flow plant fluctuates with the flow rate of the river, so it's highly recommendable to monitor these fluctuations on a sufficiently long period in order to place the turbine at a correct elevation, to correctly estimate the average head actually exploitable by the plant and consequently provide give an accurate evaluation of its technical and economical feasibility.

1.3 Limitation of the diverted flow rate

The authorisation requirement of limiting the flow rate of the reserved flow plant (in order not to exceed the maximum value of the concession) may be in contrast with the obligation of letting the "main" plant divert all the water allowed by its water concession. In fact the new diversion, to be legitimated, must not interfere with the existing one.

As already explained above, the water level at the intake usually varies with the flow rate diverted by the main plant, starting from a fixed water level (called *set point*) just upstream of the existing hydroelectric unit, so it's not possible to identify one elevation for a fixed device such as a spillway. Moreover, a fixed spillway would imply that, for river flow rates (net of the reserved flow) between the minimum and maximum discharge of the main plant, the new plant would "steal" water either from the river - by diverting more than the reserved flow - or by the existing plant - by discharging back to the river the flow rate exceeding the reserved flow and therefore belonging to the main plant.

Consequently the limitation of the flow rate diverted by the reserved flow plant usually can't be achieved by fixed devices, but only by a mechanical stop on the regulating system (runner blades or guide vanes) of the new turbine.

A possible alternative to the mechanical stop is installing regulating gates at the beginning of the existing headrace channel, in order to keep the water level constant at the weir and consequently install a fixed device, e.g. a spillway.

1.4 Interaction with fish passages

As most of these plants are built on weirs, they are often placed nearby existing or designed fish passages.

Consequently it's important to integrate the design of the structures, so the fish passage won't interfere with the plant operation but, on the contrary, the fishes will be attracted by the reserved flow released at the plant outlet.

Moreover the regulation of the upstream water level would be beneficial for the fish passage as well as for the plant operation, which is a good reason for installing the regulating gates mentioned at § 1.1, especially if the owner is the same for the main plant and for the reserved flow one.



Fig. 1. Casnigo Scarico: the reserved flow plant will be erected at the end of the tailrace channel of the main plant (whose owner is the same of the two reserved flow plants: Casnigo upstream and Casnigo Scarico downstream) adjacent to the fish passage.

1.5 Positioning

Some plants - such as Fonderia, Capriolo and Roggia Vetra - take water from the beginning of the existing headrace channel, so they're located just outside the main river bed, in order to protect them from floods and to reduce the

necessary civil works. In the case of Casnigo Valle, instead, the new plant is located on the tailrace channel of the existing plant, with very little civil works to insert the new hydroelectric unit.

1.6 Reduction of the environmental and visual impact

The hydropower plants - and even more so the ones exploiting the reserved flow released at weirs - are naturally located in the immediate vicinity of the riverbed, that is an environmentally sensitive zone; therefore various techniques have been developed for reducing their impact on the ecosystem and the landscape. With regard to the ecosystem, the impact is limited by their small dimensions and by the absence of water withdrawal in any reach of the water body; the visual impact is reduced either by “hiding” the plant (submerged solution) or by pleasantly inserting it in the local landscape, for instance covering the external structures with local stone and other materials.

1.7 Choice of the electromechanical equipment and plant layout

Submerged units, allowing for a compact plant layout, are often preferred. If a turbine with single regulation (i.e. semi Kaplan with fixed guide vanes and mobile runner blades) is employed, a gate is necessary for stopping the water flow. It's normally preferable to put the gate downstream of the turbine, so the waterways and the turbine itself remain filled with water and consequently the plant can be smoothly put back into steady operation.

The main features, advantages and disadvantage of the latest technological options are briefly discussed in § 3.

Another issue concerning the plant layout is the need to reduce the realisation complications and costs connected to the deep excavations (and the necessary retaining walls, sheet piles or micro piles) within or besides the riverbed and consequently in the presence of water.

In the end, taking into account these issues and the ones (such as environmental impact reduction) described in the previous paragraphs, the layout of the reserved flow plants should always be as compact as possible, both in plan and in vertical dimension.

The following table shows the type and configuration of the hydroelectric unit (along with the characteristic heads and flow rates) which have been chosen for the aforementioned representative plants exploiting the reserved flow.

<i>Name of the plant</i>	<i>Maximum flow [m³/s]</i>	<i>Average flow [m³/s]</i>	<i>Gross head [m]</i>	<i>Hydroelectric unit (type and configuration)</i>
<i>Casnigo Scarico</i>	1,64	1,64	3,05	Vertical Kaplan with external generator and belt drive
<i>Casnigo</i>	1,58	1,58	5,20	Vertical Kaplan with external generator and belt drive
<i>Parre</i>	3,00	1,89	4,30	Vertical Kaplan with external generator and belt drive
<i>Prato Mele</i>	2,46	1,90	4,70	Vertical Kaplan with external generator and belt drive
<i>Fonderia</i>	2,45	2,45	3,50	Vertical Kaplan with external generator and belt drive
<i>Esine</i>	4,50	3,10	4,20	Vertical Kaplan with submerged generator
<i>Capriolo</i>	10,00	4,13	5,90	Vertical Kaplan with submerged generator
<i>Roggia Vetra</i>	10,00	6,54	6,30	Vertical Kaplan with submerged generator
<i>Urago</i>	12,00	10,21	3,50	Horizontal S-Kaplan with external generator
<i>Carema</i>	24,00	16,48	4,00	Inclined Kaplan with submerged generator
<i>Chievo</i>	56,10	56,10	3,10	StrafloMatrix™ (array of propeller units)

2. Case studies

Among the plants presented in the previous table, a few examples of different schemes are described in detail.

It's interesting to notice all of these reserved flow plants will have the same owner as the main plant. That's why in some cases - e.g. Casnigo and Carema - the regulating gates (hydraulically operated) mentioned at § 1.1 will be installed at the beginning of the existing diversion waterways.

2.1 Casnigo Scarico - Casnigo - Parre - Prato Mele - Fonderia

These projects have obtained all the necessary authorisations and are currently under construction. All these plants will have a vertical axis Kaplan turbine coupled by belt drive with an external generator, resulting in a very compact layout. Thanks to this some of them, such as Prato Mele and Casnigo, could be placed on one extremity of the existing weirs, in place of the short flushing canal collecting water from the sluice gates or the spillways located just upstream of the existing diversion channels.

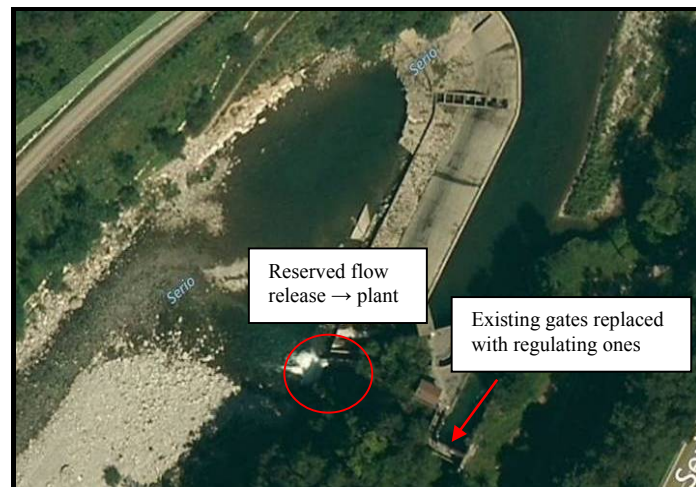


Fig. 2. Casnigo: the on/off gates at the beginning of the headrace channel of the existing plant (whose owner is the same of the reserved flow plant on the left side of the existing weir) have been replaced with regulating ones, hydraulically operated.

2.2 Capriolo - Roggia Vetra

In both of these plants, located along the Oglio river, downstream of the Iseo Lake, a vertical Kaplan unit will be installed, directly coupled with a submerged permanent magnet generator.

2.3 Urago

This is the only example, among the ones listed in the table, where a turbine with horizontal axis will be employed; in particular two S-Kaplan units will be installed, directly coupled with external generators. This plant - like those of Capriolo and Roggia Vetra, located upstream along the same river, the Oglio - will be placed at the beginning of the existing diversion channel, thus protecting it from the strong river floods.



Fig. 3. Example of the horizontal S-Kaplan unit, directly coupled with external generator, like the one in Urago DMV plant.

2.4 Chievo

It's a particular case, with a very large flow rate (actually this isn't properly a *mini* hydro plant) and an innovative technical solution, the StrafloMatrix™, that is an array of small propeller turbine-generator units, allowing for compact construction - thanks to the permanent magnet generator with the rotor integrated into the turbine runner - and the possibility to lift and lower the structure (steel module) in a few minutes, just like a gate. The plant has already been operating for nearly five years, since October 2009.

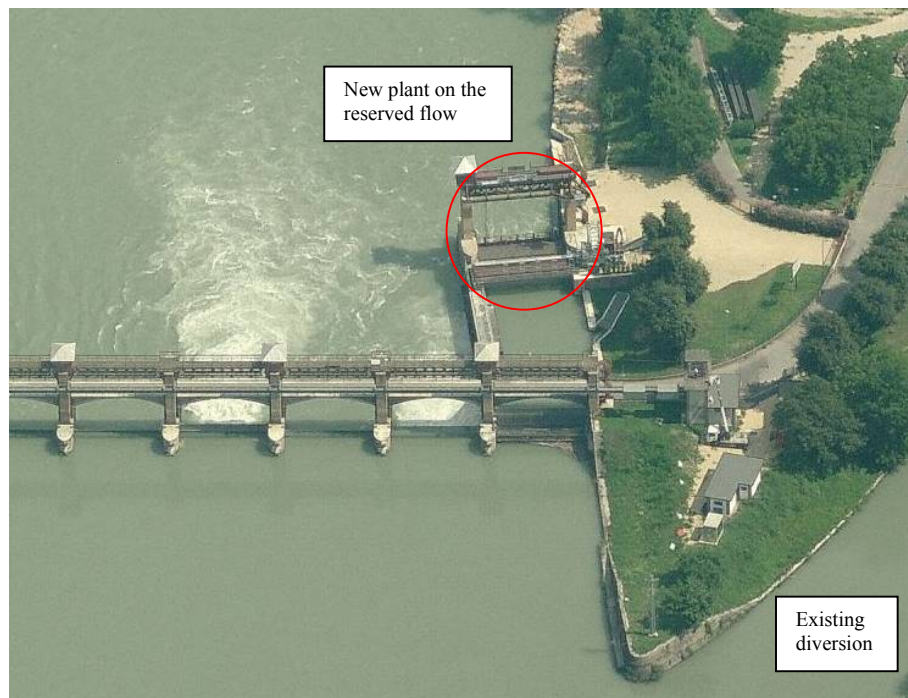


Fig. 4. Reserved flow plant built in the old ship lock at Chievo Dam, on the Adige River, just outside the city of Verona. The headrace channel of the main plant (located in the centre of Verona) is located on the right side of the river.

3. Recent technological developments

The main technological development in the small hydropower sector in the last decade have concerned low and very low head applications. The most important ones are described in the following paragraphs.

3.1 Permanent Magnet Generators (PMGs)

It allows for the direct coupling between turbine and generator with a little encumbrance. Moreover, thanks to the absence of sliding parts, they have a high efficiency (~90% in the design head and flow rate conditions) and they require very little maintenance. These positive features make them a good - although expensive - choice also for small plants as usually are those which exploit the reserved flow.

Among the aforementioned plants, those of Esine, Roggia Vetra, Capriolo and Carema (and also Chievo, with its particular equipment) employ Kaplan units with submerged PMGs, as described in the previous paragraphs.

3.2 Belt Drive

Actually this is an old technology, which has become much more reliable (due to improved belt materials, reinforced with carbon fibres) and has been employed in many recent applications, such as those under construction (or ready for construction) at Casnigo, Prato Mele, Parre and Fonderia. Its advantage is that it allows for a compact layout of the hydroelectric group, without any gearbox. Its disadvantage is that, compared to other technologies, it has a low global efficiency, i.e. no more than 80% in the design head and flow rate conditions.

Anyway, taking into account the requirement of reducing the dimensions - both in plan and in vertical - of the plant, for the reasons explained in chapter 1, the belt drive can often be a sensible choice.

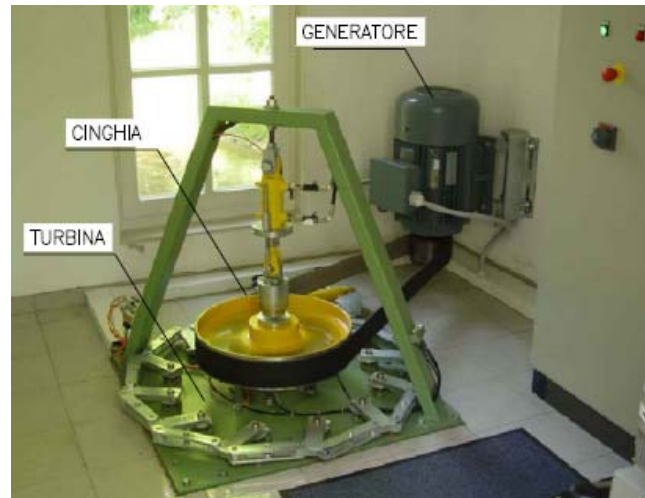


Fig. 5. Example of vertical axis Kaplan unit with belt drive and external generator.

3.3 Very Low Head (VLH) Turbines

They are suitable for large flow rates, no less than $10 \text{ m}^3/\text{s}$, and of course very low ($\sim 1\text{-}3 \text{ m}$) heads; therefore they are usually employed only on large rivers. In such cases they may be an alternative to the other types of turbines described in the case studies and listed in the table above.

An important advantage of VLH turbines is that they require very little civil structures: in fact one simply has to fix a steel frame with a runner to the (usually) already existing walls or structures, as shown in the picture below.



Fig. 6. Example of VLH installation.

3.4 Others

Certainly other types of technical choices - concerning the hydroelectric units and, consequently, the plant layout - are possible for peculiar cases: for instance siphon turbines to be installed over the weir, or cochlea turbines for very low heads (or else the Archimedean screw would become excessively long) and low flow rates.

4. Authorisation and tariff frame

The “boundary conditions” are as much important as the aforesaid technological developments for the expansion of reserved flow exploitation, because the easiness of realisation makes attractive also some plants which otherwise (e.g. if they were “normal” plants, requiring new diversions) wouldn’t be very profitable.

The most important ones are listed in the following paragraphs, with reference to the Italian context.

4.1 Authorisation

In some Italian regions, the hydropower plants exploiting the reserved flow of existing diversions have a somehow “easier” authorisation path, because they’re exempted from the Environmental Impact Assessment.

4.2 Tariffs

Reserved flow plants in Italy are one of the categories which have *priority* access to the incentive system; moreover, for nominal (something like average) capacity under 250 kW - or 500 kW if the owner is a public authority, such as a municipality - they have *direct* access to the incentives, i.e. without passing by the present standard procedure, which implies incentive allocation according to the order and priority of inscription into the relevant registers.

Another priority factor is to be built on existing (and unmodified by the project) weirs or dams, which is often the case for reserved flow plants.

Therefore these plants, even if they aren’t very profitable by themselves, they may prove preferable - compared to larger HP plants - for investors and financiers, due to the somewhat lower incertitude of the path leading to the authorisation, realisation and commitment of the plant.

Finally the following table depicts the technical-economical picture of the examined plants.

<i>Name of the plant</i>	<i>Cost of design and realisation [€]</i>	<i>Installed capacity [kW]</i>	<i>Cost/capacity [€/kW]</i>	<i>Expected yearly energy production [kWh]</i>	<i>Cost/energy [€/kWh]</i>
<i>Casnigo Scarico</i>	480.000	40	12.000	330.000	1,45
<i>Casnigo</i>	500.000	70	7.140	570.000	0,88
<i>Parre</i>	880.000	98	8.980	540.000	1,63
<i>Prato Mele</i>	460.000	94	4.895	617.000	0,75
<i>Fonderia</i>	539.000	70	7.700	595.000	0,91
<i>Esine</i>	1.100.000	155	7.095	890.000	1,24
<i>Capriolo</i>	1.870.000	480	3.895	1.700.000	1,10
<i>Roggia Vetra</i>	2.090.000	600	3.485	2.766.000	0,76
<i>Urago</i>	1.680.000	350	4.800	2.400.000	0,70
<i>Carema</i>	4.755.000	770	5.875	4.650.000	1,02
<i>Chievo</i>	10.000.000	1.480	6.760	12.000.000	0,83

5. Future exploitation perspectives

In the light of the ongoing technological development in the Small Hydro field and of the “boundary conditions” described above, the perspectives for the future exploitation of the reserved flow, with particular reference to the Italian context, are mainly focused on low (or very low) head plants built on existing weirs or at the beginning of existing diversion channels, because the other schemes - such as high head plants exploiting the flow released from dams - are more demanding from the financing, authorisation and realisation point of view.

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