

# Low and very low head SHPP: Where is the efficiency hiding? Overview on several case studies

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During the years of professional activity, the lack of efficiency in low head hydropower plants has been recognized as one of the most recurrent faults in the hydropower field. At the reckoning, several low head HPPs have not been able to keep their promises in term of efficiency. It's not uncommon that this kind of plant has efficiency and operation problems, sometimes so serious as to compromise the validity of the whole initiative.

After a brief description of some of the possible existing technical solutions, the paper will analyse in detail 3 case studies in which problems of efficiency and operation were found.

The results of the analysis, aimed to identify the causes of the detected efficiency and operation problems show that those causes are mainly due to:

- i. Civil and hydraulic design
- ii. Quality of the water

## **1. Background**

### **1.1 Existing technologies**

There are several types of turbines which are currently employed in the low head segment as well as a number of experimental machines.

The most frequently proposed turbine are different configurations of *Kaplan turbine* and the *Archimedes screw* working in reverse as power generator. Developed in this decade's *VLH turbine*®, *Matrix*® and *Vortex turbine* are proposed for the application in case of low and very low head as economic and effective solutions.

*Axial flow turbine*: A Kaplan turbine is basically a propeller with adjustable blades inside a tube. Typically, they are used on sites with net heads from 1.5 to 20 metres and peak flow rates from 1 m<sup>3</sup>/s to 30 m<sup>3</sup>/s.

Those high efficiency turbines are slow speed machines and requires a gear box for speed increase to use standard generators.

The standard configuration, with adjustable guide-vanes and blade allow for a higher flexibility in term of performance in head and discharge variable conditions but on the markets, there are also variants of Kaplan turbine that only have adjustable inlet guide vanes or adjustable rotor blades which are known as semi-Kaplan's. Although the performance of semi-Kaplan's is compromised when operating across a wide flow range, for applications where the flow does not vary too much they can be a more cost-effective choice [1].

Furthermore, Kaplan turbines are available in three basic configurations: vertical axis, horizontal axis (or S-turbines) and bulb turbines.

Vertical-axis Kaplan's have the advantage of requiring the smallest footprint or land-take. The Kaplan turbine is built into the concrete structure, with the inlet volute (basically a snail shell shaped pipe that wraps around the inlet guide-vanes and distributes the water equally around the whole circumference) and draft tube cast into the concrete at the construction phase. So critical is the perfect geometry of the intake volute and draft tube that it is normal practice for the turbine manufacturer to supply the wooden formwork for these parts to be used by the civil engineering contractor.

Horizontal axis or 'S-turbines' and bulb turbines are technically slightly more efficient than vertical axis Kaplans because the inlet flow does not have to change direction so should have lower hydraulic losses. In reality, there is no

discernible difference, so the decision on the orientation is normally made through choice of supplier and price. S-turbines do require a larger system footprint which can be a disadvantage in space-constrained sites.

Bulb Kaplan turbines have all of the drive system and generator accommodated inside a streamlined 'bulb' that sits within the main flow. They are only practical on large hydro projects where it is physically possible for a person to climb down into the bulb for maintenance.[1]

*Archimedes screw:* Archimedes screw is a typical gravitational engine. The shaft driving torque is due to the weight of water moving downwards in the buckets formed by the screw blading. Fish passage downstream is possible and due to the low mortality and moderate injury rate they are considered as fish friendly.

These machines are built for head differences from 1.2 to 10 m and power ratings from 5 to 300 kW.

From the technical point of view the high advantage is relatively high and flat efficiency characteristics, generally keeping in the 80 ÷ 90 % range for discharges above 25 % rated value. Typical efficiency of the whole hydroelectric unit is between 75 and 85 %. The disadvantages of rather limited regulation capabilities and high gear ratio could have been substantially mitigated by the use of frequency converters which allow also for rotation speed control.

In numerous cases they are considered a low cost and environmentally acceptable alternative for a classic axial flow turbine.

*Matrix®:* This solution consists of a single or a set of small turbine-generator which are inserted into the gate slots of existing dam and waterways. Since no new, significant civil structures are needed, this technology enables customers to instal hydroelectric power plants at far more competitive costs and with minimal environmental impact compared with conventional plants.

The Matrix unit consist of a stay ring with fixed stay vanes, a fixed blade propeller type runner and a generator directly connected to the turbine runner.

The supporting module consists of a stiff, steel fabricated structure, which supports the turbine-generator units. The module also includes steel fabricated draft tubes with integrated control gates.

*VLH turbine®* This unit are an integrated generating set incorporating a Kaplan runner with adjustable blades, a fixed distributor and flat bars inserted in between the wicket gates as trash racks, a permanent magnet generator directly coupled to the runner shaft and an automatic trash rack cleaner mounted on the distributor. The specific design allows to eliminate the need to have sophisticated civil engineering structures for the inlet to, and exit from, the runner. The unit is fully submersible, which allows for negligible visual and sound impacts. [2]

The main purpose of this machine is to harness the low head potential created by small weirs furnished with regulating gates. The concept was to replace the existing gate by a flap one comprising a large diameter axial-flow hydraulic unit with adjustable runner blades and variable speed permanent magnet generator. No civil engineering intervention except replacement of the gate is needed. Furthermore, low runner speed allows for keeping high efficiency without a draft tube and to avoid injuring fish passing the turbine. The unit is recommended for operation with heads between 1.4 and 3.4 m.

*Vortex turbine:* in the recent years several research activities allow to develop this new kind of turbine able to exploit energy from water whirlpool. This innovative compact solution is available for head ranging from 0.5 to 4 m and discharge from 0.5 to 5 m<sup>3</sup>/s.

The civil works needed are very few and are constituted by a small branch-way next to the water course and a trash rack. The whirlpool is created into a spiral-shaped basin at the end of the canal then, thanks to a runner the rotation is converted in energy. The turbine is completely submerged, and it has been designed to withstand any type of flood.

*Summary of very low head hydropower converter characteristics, with machine efficiency, ecological characteristics in relation to fish passage (impacts: high, low, medium), costs (high, medium, low) and allowing of sediment passage (Yes or Not). The turbine type can be Hydrostatic/Gravity (H), Reaction (R) or Action (A). [3]*

| Type              | H (m)      | Q(m <sup>3</sup> /s) | h (%)  | Costs | Fish | Sediments | Type |
|-------------------|------------|----------------------|--------|-------|------|-----------|------|
| Kaplan            | 1.5 – 20.0 | 1.0–30.0             | 82–92  | H     | M    | N         | R    |
| Archimedes screws | 1.0 – 6    | 0.1–5.5              | 75–85  | M     | L    | Y         | H    |
| VLH® Turbine      | 1.4 – 4.5  | 10.0–30.0            | 80–91  | L- M  | L    | N         | R    |
| Matrix® Turbine   | 2.5 - 20   | 5 – 12.5             | 80 -90 | M- H  | L    | Y         | R    |
| Vortex turbine    | 0.5 - 4    | 0.5–5.0              | 40–50  | M     | L    | Y         | A/R  |

## 2. Case study

### Case study No.1

#### ***Description of the plant/s***

The first case study presents two-twin SHPPs. The plants have been completed in 2020 with the aim to exploit the residual hydroelectric potential across two existing weirs used for agricultural purpose.

The main figures of the projects are summarized below:

|                            | <i>Case1.a</i>       | <i>Case 1.b</i>      |
|----------------------------|----------------------|----------------------|
| Max. Discharge             | 15 m <sup>3</sup> /s | 15 m <sup>3</sup> /s |
| Rated head                 | 2.3 m                | 1.6 m                |
| Rated power                | 305 kW               | 212 kW               |
| Expected energy production | 1.1 GWh/y            | 0.69 GWh/y           |

The two plants are equipped with a Kaplan turbine with horizontal axis and a runner diameter of 1778 and 1780 mm respectively. The turbines have been completed with an extremely long draft tube (10 m) to maximize the efficiency of the turbine.

The civil layout, specifically designed to minimize head losses in the waterways, is characterized by a large intake (more than 16 m wide) and respectively 22 and 24 m inlet channel length in which take place the main gate and the trash rack equipped with an automatic trash rack cleaner. The width of the channel varies gradually from 16 m (at the intake) to 6 m (in the final section). The depth varies from 1 m at the intake to about 6 m close to the turbine. The tail races have a length of 14 and 16 m respectively. Depth and width vary gradually along the tail race. Width of the restitution channel varies from 6 m (close to the end of the draft tube) to 15 m at the restitution point. Depth is about 3 m, close to the tailrace, and decrease gradually to ensure a smooth joint with the existing riverbed.

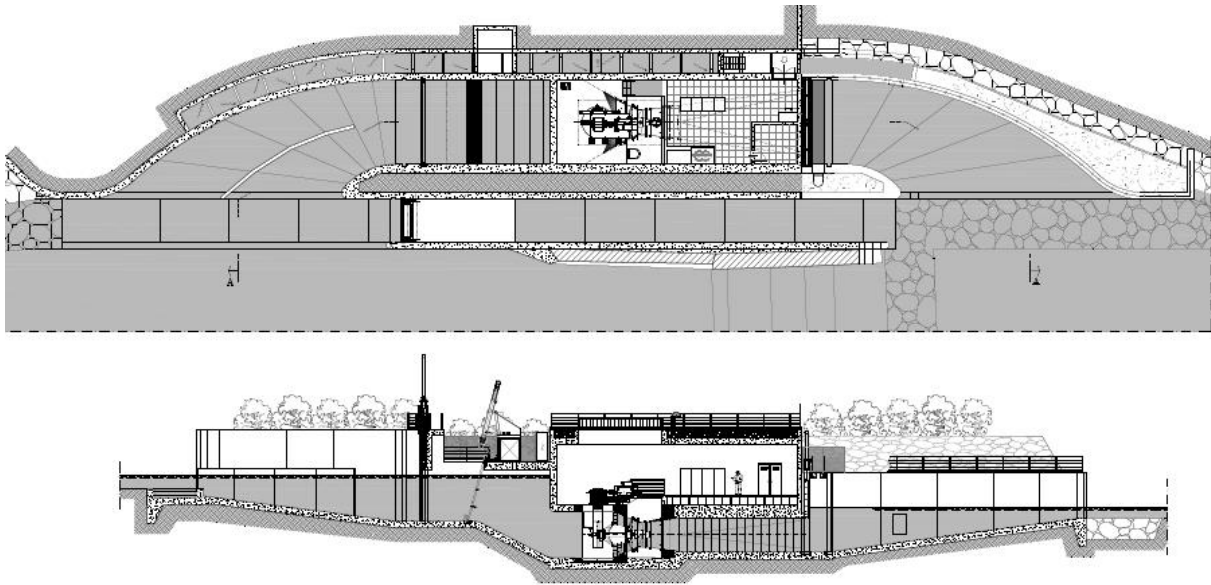


*Fig. 1. Plan and cross section view of the 1.a case study plant*

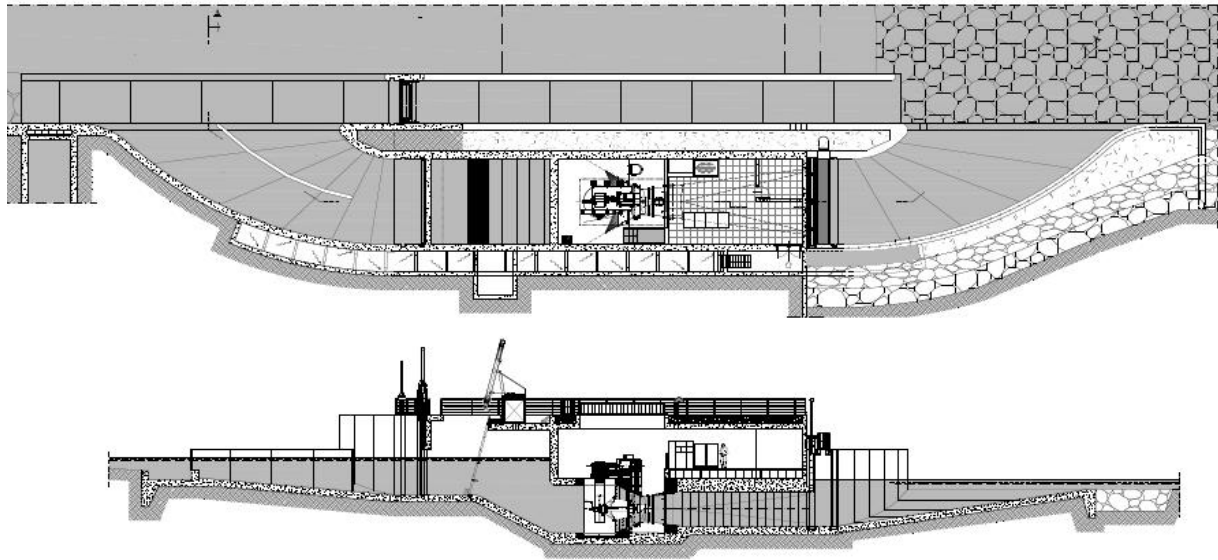


Fig. 2. Plan and cross section view of the 1.b case study plant

### Exhibited problems

From the start-up of the plants, both the turbines show the following problems:

- Failure to reach and maintain the maximum power (proven the availability of flow rate and head)
- Efficiency well below to the contractual one
- Remarkable drop in the generated power of the turbine during time in stable condition of head and flow rate.

Summary of the efficiency in different working conditions for turbine and generator for the two case studies.

In the table it has been reported the guaranteed group efficiency and the group efficiency estimated starting from the data obtained by the plant on-board instruments

| Load   | Case 1.a |      |              |              | Case 1.b                    |             |              |              |
|--------|----------|------|--------------|--------------|-----------------------------|-------------|--------------|--------------|
|        | Q        | H    | $h_g$<br>(%) | $h_e$<br>(%) | Flow<br>(m <sup>3</sup> /s) | Net<br>head | $h_g$<br>(%) | $h_e$<br>(%) |
| 100%   | 15.00    | 2.10 | 85.16        | 75           | 15.00                       | 1.36        | 81.90        | 57           |
| 75%    | 11.25    | 2.20 | 85.91        | -            | 11.25                       | 1.47        | 84.78        | -            |
| 50%    | 7.50     | 2.31 | 83.52        | -            | 7.50                        | 1.60        | 83.40        | -            |
| 27.78% | 4.17     | 2.42 | 73.39        | -            | 4.17                        | 1.72        | 76.85        | -            |

### Countermeasures taken

Due to the efficiency fault detected, an extensive inspection plan has been carried out on the plants.

The analysis performed included:

- i) Check of the accuracy of the existing head
- ii) Site inspection focused on the detection of abnormalities in the turbine functioning
- iii) Optimization of the runner and wicket gates curve.

*Check of the accuracy of the existing head:* the fault in the determination of the design head in low head HPP is one of the major and most common mistakes that could be done by the designers. If the upstream level is, generally, quite easy to be determined been kept fixed by the turbine regulation, the downstream level is determined by the topographic and morphologic conditions of the river downstream to the weir as well as the discharge and, thus, it is not so easy to be determined. Since the nominal head of those plants is small (generally in the order of few meters) an error in the determination of the head during the design phases, even of few centimetres, could be, in percentage not negligible and strongly affects the energy production of the plant. Furthermore, since this kind of turbines are specifically designed for a certain head, deviation from the design conditions could lead to a decreasing in efficiency of the turbine.

For the presented case studies, the head measured in the campaign has been found about 30-50 cm lower with respect to the one assumed in the design (in both the plants). A deeper analysis revealed that the variation in the expected

water level downstream should be attributed to the change on the river bottom elevation with respect to the one surveyed in the design phase (2015). This variation is mainly due to the sedimentation, downstream to the weir, of sand and gravel transported during the floods by the river. This phenomenon has been enhanced during the execution of the works due to the presence of the earth cofferdam realized to protect the construction site from the river that was eroded several times during flood events.

The problem has been solved bringing back the riverbed at the elevation measured in the survey of 2015. The intervention was successful, and the design head has been recovered. Despite that, the efficiency of the turbine was not increased.

*Site Inspection:* due to the permanence of the efficiency problems on the turbine the manufacturer performed inspection on the sites. Measure of all actuators strokes and hydraulic cylinders has been performed together with the gap of the impeller blades. Furthermore, a visual inspection of the waterways and turbine has been carried out. During inspection no abnormalities or any disturbing noise has been detected.

Unexpected amount of grass trapped in the trash rack and in the river has been found. Furthermore, the difference of the level behind the trash rack was constantly high showing high clogging of the trash rack and lot of debris in the river.

The visual inspection resulted, also, in the evidence of some sand and gravel sedimented in the inlet channel (for site 2 which waterways has been dried to perform the inspection).

For site 2, during the visual inspection, a damage in the paint of the discharge ring was detected.

The measure of the blades gaps in each blade position gets the evidence in a lack in centring of the discharge ring. To produce an optimum setting for permanent operation, the discharge ring has been re-centred.

In both plants significant power increase after shutdown of the turbines were noticed during the analysis of the SCADA records. The re-gain of power in site n. 1 went up to 70/80 kW after restart of the turbine while in site n.2 it has been of 30 kW. Despite that after few minutes the power gradually decrease to not normal low value.

*Optimization of the runner and wicket gates curve:* The tests to adjust the runner - wicket gates correlation via SCADA should make it possible to increase the turbine's performance. For this purpose, the assignment of both parameters to each other was changed using a table and iteratively determined at which interaction the highest power can be achieved.

After the on-site intervention at both plants and after the attempted adjustment of the conjugation curve, there was no significant increase in performance.

At the date no definitive solution has been found and efficiency at the plants are still well below to the contractual one.

The explanation provided by the manufacturer takes into consideration the conditions, in terms of type and quantity of the solid transport of the river.

The manufacturer underlines that, in connection with the additional surface pollution by green cuttings, grasses, branches and others, a clogging effect may occur in the area of the rake, the distributor or the runner of the turbine. This sediment type could enhance the formation of nests which can grow steadily due to the missing effective flushing process. This thesis could be confirmed, according to the manufacturer, by the fact that under same hydraulic conditions (same wicket gates opening – same head) at different times and days the power assumes very different values, not explainable from a fluid dynamic point of view in presence of clean water.

As a result of the analysis performed by the manufacturer, he proposes the following action:

- i) Implementation of the flushing cycle which is not implemented in the standard configuration
- ii) Review of the rake existing bar spacing and consideration of the optimal bars spacing. Check if the cleaning capacity and/or speed of the trash rack machine is suitable for the kind of solid transport in the river
- iii) Check and revision of the standard clearance between impeller blades and discharge ring according to the intense solid transport in the river.

## Case Study No 2

### Description of the plant/s

The HPP, designed in 2014 and in operation since 2016 has been designed to exploit the residual hydroelectric potential constituted by the Environmental flow released at the intake of an existing plant.

The main figures of the project are summarized below:

|                            |                      |
|----------------------------|----------------------|
| Max. Discharge             | 10 m <sup>3</sup> /s |
| Rated head                 | 6.3 m                |
| Rated power                | 600 kW               |
| Expected energy production | 2.76 GWh/y           |

The intake of the plant is placed on the opposite side of the headrace canal of the main plant and diverts water to the new plant thanks to a short headrace channel 30 m long, 5.5 m wide and 2 m deep. In the channel takes place the main gate and a screen with automated trash rack cleaner to prevent debris and other floating material enter in the turbine.

At the end of the head canal a squared load chamber has been designed as connection between the channel and the turbine.

The tail race is hydraulically shaped in order to minimize head losses and it is shown in the figure below.

The hydraulic layout of the tailrace has been also subject of CFD analysis to verify and minimize the hydraulic losses.

The HPP is equipped with a vertical semi-Kaplan submersible unit with regulation on runner blades. Diameter of the runner is 1447 mm.

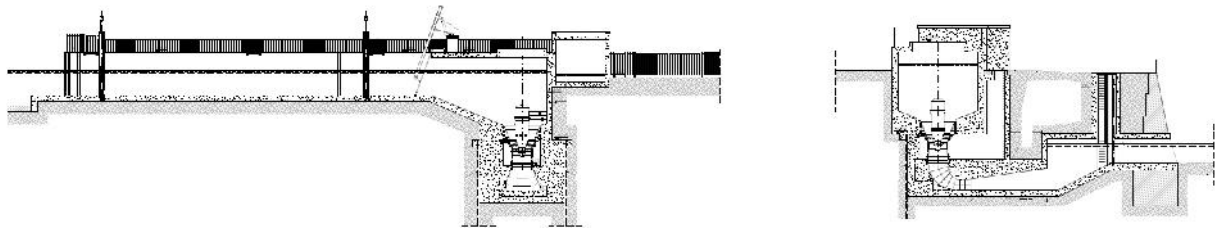


Fig. 3. Plant cross section of the second case study

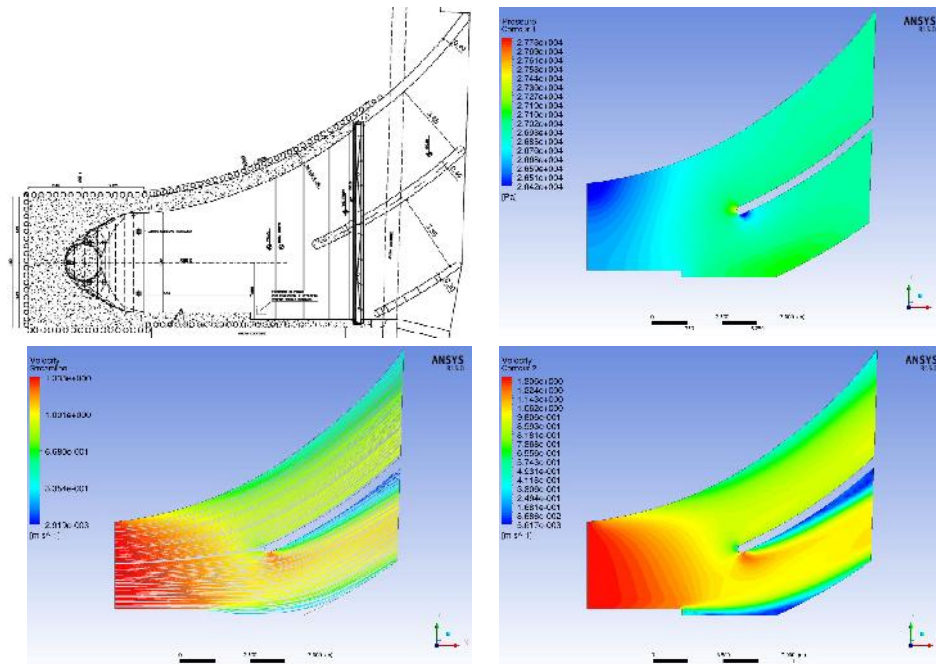
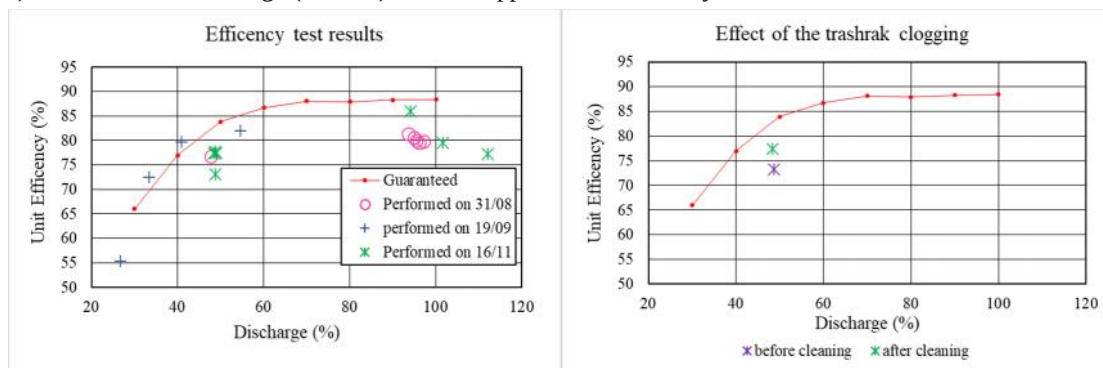


Fig. 4. Tail race geometry and hydraulic optimization study. Pressure and velocity distribution form the CFD simulation performed ( $H$  6.4 m and  $Q$  11 m<sup>3</sup>/s)

### Exhibited problems

The efficiency tests performed (and repeated several times) show, together to the lack in the efficiency of the plant, several other problems:

- i) The trash rack is often found clogged by floating material such as plastics, branches and grasses. The reduction in efficiency due to this has been quantified since tests have been performed even after the cleaning of the trash rack. In conditions of clean rack the efficiency of the turbine raises even more than 3%.
- ii) By increasing the derived discharge, turbulence appears in the inlet channel. The discharge measure show that the approaching velocity of the water is higher than 1 m/s with a strong preference of the water flow in the right part of the channel. This has been explained by the presence of the irrigation channel intake to the left of the power plant which causes a separation of the flow. The suffering of the inlet channel is shown also by the difficulty of the unit to regulate at the maximum discharge and by the several shutdowns for minimum head recorded.
- iii) At maximum discharge (11 m<sup>3</sup>/s) a vortex appears in the forebay of the turbine.



### Countermeasures taken

Together with the Client and to the Manufacturer the following correction measure has been taken:

- i) In order to decrease the floating material load on the trash rack a floating debris barrier has been installed at the intake of the new plant.
- ii) Anti-vortex structure has been installed in the turbine forebay in order to avoid their formation. This solution allows to avoid all the unwanted effects of the vortex (vibration, noise, power fluctuation, structural issues) on the turbine.

The adopted solution led to an accetable condition. The installation of the floating debris barrier allows to decrease the sediment load on the trash rack gaining some percentage in efficiency.

The installation of the Anti-vortex structure allows for a safer operation of the unit.

Unfortunately, no corrective measure has been founded in order to face the turbulence and the unbalance of the approaching flow in the channel.

### Case study No3:

#### Description of the plant/s

The plant, designed in 2017, has been realized with the aim to exploit the existing residual hydroelectric potential across an existing weir over a variable head according to the discharge.

The main figures of the project are summarized below:

|                            |                      |
|----------------------------|----------------------|
| Max. Discharge             | 15 m <sup>3</sup> /s |
| Rated head                 | 2.45 m               |
| Rated power                | 360.29 kW            |
| Expected energy production | 1.21 GWh/y           |

The plant has been equipped with a Kaplan turbine with horizontal axis designed preferring the operation at partial flow rates. The installed turbine has a diameter of 1450 mm and a compact drafttube about 5 m long complete the turbine layout.

The civil and hydraulic layout of the plant is the common adopted for this kind of turbine and is reported in the figure below. The intake is located just upstream to the existing weir, the inlet channel is 12 m long, 3 m depth and it has a variable width from 13 to 4.40 m.

At the inlet of the channel is located a trash rack equipped with an automatic cleaner to prevent debris and other floating material to enter in the plant waterways. The trash rack has been designed with horizontal bars. The tail race of the plant is a channel 12 m long and 5.10 depth with a variable width from 4.40 to 11.40 m respectively close to the draft tube and at the restitution.

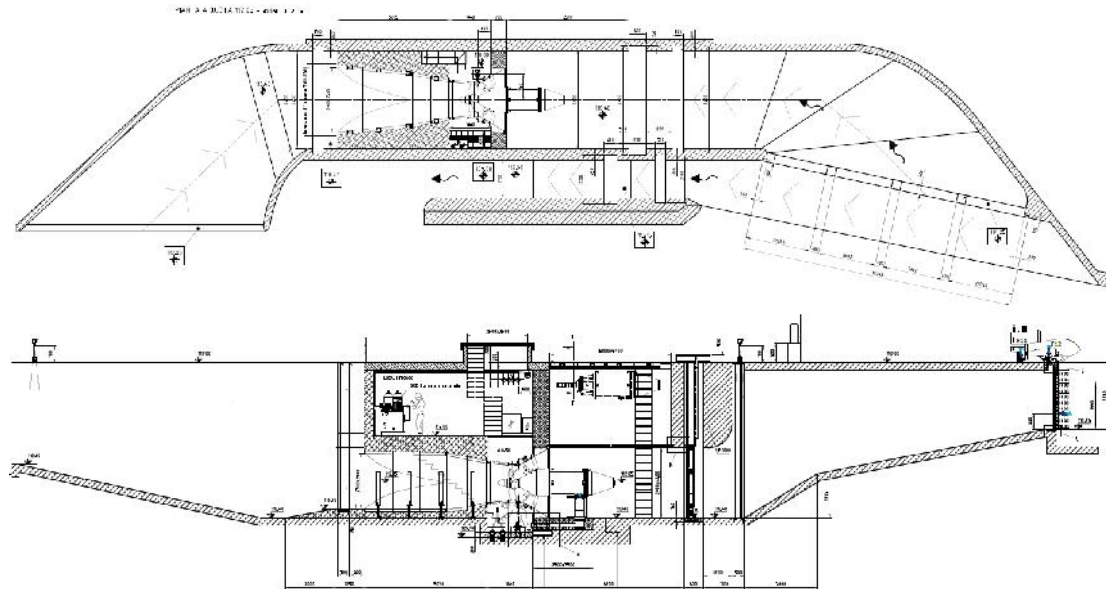


Fig. 5. Plan and cross section view of the 1.a and 1.b case study plants.

### **Exhibited problems**

The turbine exhibited the following problems:

- Failure to reach and maintain the max. power stably (proven the availability of flow rate and head)
- Remarkable drop in the generated power of the turbine during time in stable conditions of head and flow rate
- Increasing with time of the axial vibration
- Remarkable drop in the generated power at the increase of the submergence

### **Countermeasures taken**

The analysis performed by the manufacturer, which include a CFD simulation and on-site inspection aims to formulate the following hypothesis and considerations:

- i) Water has an important solid transport (suspended objects, colour etc.)
- ii) The water has also a strong entrainment of air as it passes through the grid
- iii) Non-optimal inlet conditions affect the turbine efficiency
- iv) Hidden losses along all the waterways decrease the available head across the plant.

The CFD simulation has been performed with an assumed flow rate of 15 m<sup>3</sup>/s and a net head of 2.16 m.

Bi-phase model has been realized and pressure boundary conditions has been set upstream and downstream to the model.

The simulation results in a depression of the free surface of about 0.2 m due to the velocity increase at downstream corner of the intake.

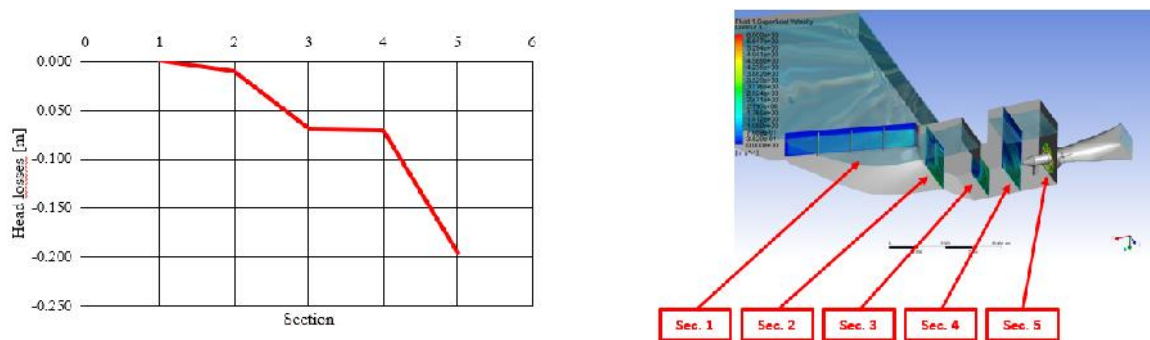


Fig. 6. Head losses progression along the head canal from intake to turbine front section

Furthermore, the simulation shows an important vortex formation in the inlet channel upstream to the turbine and a non-uniform distribution of the flow with an important separation of the flow from the left wall of the channel. The behaviour of the flow in the channel is reflected at the inlet of the turbine where a non-uniform pressure distribution and velocity has been detected.

Considering the impossibility to modify the hydraulic design of the waterways, to date the plant continue to suffer the efficiency problems listed above.

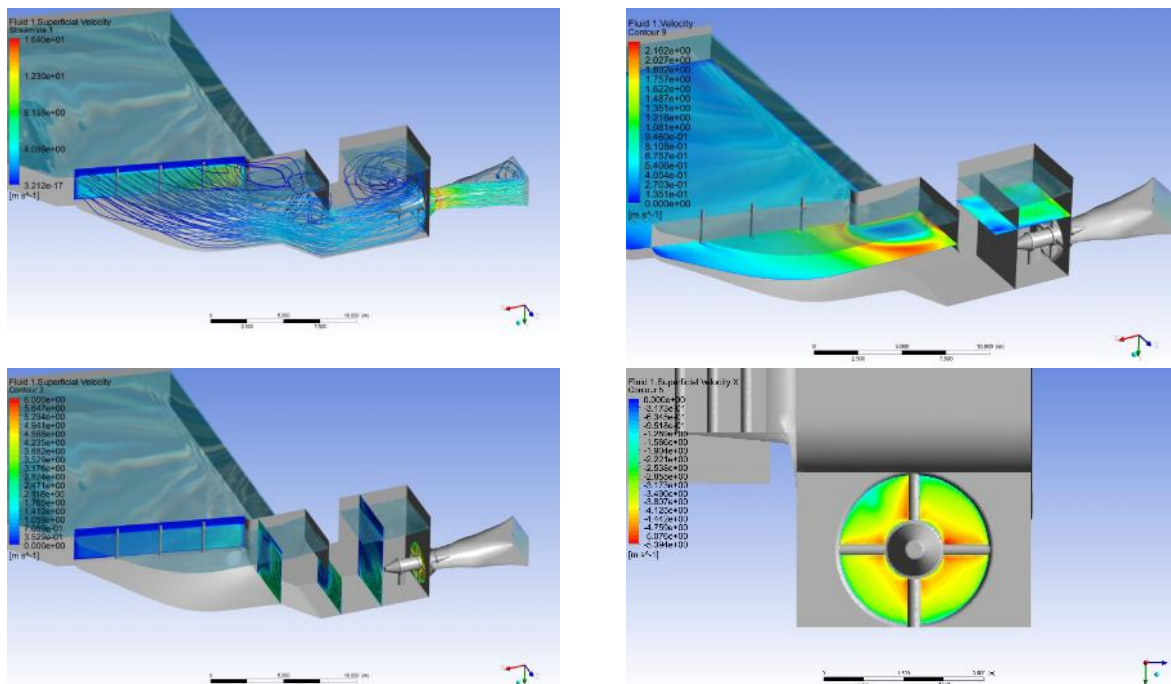


Fig. 7. Velocity distribution in the head canal of the plant. CFD analysis performed by manufacturer (Net head 2.16; Discharge 15 m<sup>3</sup>/s)

### 3. Conclusion

Even if we are used to consider the technology for low head and very low head HPP as mature, efficiency problems on these plants are more common than what could be expected.

Failures in the efficiency of the plants are generally not due to a single cause but by a combination of factors. That makes difficult, and time consuming, identify the solution causing, in addition to the direct costs for the implementation of the correction measures, a not negligible loss in the production and, consequently, in the income in the first years of the plants.

The cases study presented well describe the results of our experience as designer and hydropower experts according to which, efficiency and operation problems in small head hydro power plants are mainly related to two different factors:

- Civil and hydraulic design: it could affect mainly the available head and the uniformity (i.e. symmetry) of the approaching flow (and in cascade the efficiency of the turbine)

An error in the evaluation of the available head could occur both for an error in the evaluation of the water level downstream and for an underestimation of the head losses in the plant waterways. Missing in the evaluation of the correct available head has a double negative effect on the plant production: a) generate less production since head is lower, b) could let the turbine work in a not optimize head range so that turbine efficiency suffers.

On the other hand, the design of not hydraulically shaped waterways could lead in generalized or localized turbulence in the approaching flow. This could lead to an increasing of the head losses (see above about the consequence) but also in a direct decreasing of the efficiency of the turbine which is forced to work in a non-uniform approaching flow condition.

Sometime, this failure could be faced by installing anti- vortex structure but in the majority of the cases being the fault in the design structural (i.e. inlet channel too short or not hydraulically shaped, inlet velocity too high etc.) there is not an easy solution and, generally, problems accompanies the whole life of the plant.

Another important issue in the design of small HPPs is the choice of the turbine type. The maximum efficiency value reachable couldn't be considered as the only effective parameter. Effective operation range of the unit chosen in term of head should be carefully considered together with the flexibility of the unit. Furthermore, the possible integration with the existing structures must be considered in order to minimize land acquisition and civil works and definitely, the cost of the realization of the plant.

From the case studies proposed the following lesson can be learnt regarding the civil and hydraulic design:

- *Geometry of the waterways affect dramatically the behaviour of the approaching water and, in the end, the efficiency of the plant. Since this is a boundary between the scope of work of the turbine manufacturer and the civil designer it is a very critical point that should be studied carefully in order to avoid vortexes and ensure the best possible approaching conditions.*
  - *Horizontal axis Kaplan turbine seems to reach its lower boundary of working range close to 2.5 m of head. For lower head different solution both, more economics and efficient, may be considered.*
  - *The riverbed configuration downstream to the plant is crucial in order to obtain the design head. Due to the time necessary from the survey to the construction and due to the material released during the flood occurred within the construction period is common to detect a modification of the riverbed downstream to the plant. This change of the boundary condition could lead to an increased water level downstream to the plant and, consequently, an head decrease.*
- Quality of the water: the type and amount of sediment could affect the efficiency and operation of the plants. The parameter that should be considered is the transported material load. Here a differentiation between material dragged by the current on the riverbed (such as sand and gravel) and suspended material (such as debris, trash, algae etc..) must be done.

Sand and gravel could enter in the waterways diminishing the effective flow area inducing head losses and turbulence in the incoming flow. Sand and gravel could also get stuck in the gap between the blades and the cover of the turbine causing friction and consequent efficiency reduction of the unit.

The transport of solid material in the plant waterways is much higher during flood or at the very beginning of the plant life where the new river transport balance has to be reach yet but is present also during normal operation of the plant.

Specific design of the intake (where it is possible) must be done in order to avoid as much as possible the entrance of dragged material in the plant waterways providing steps and disconnection between plant waterways and riverbed. Where the site condition doesn't allow for that, frequent de-sanding cycles must be performed and operation during flood or in presence of high sediment transportation load should be avoided.

Suspended material such as plastics, levees, grasses etc. generate mainly operation problems instead. Generally, this kind of material is intercepted by the trash rack which has the function to prevent the entrance of such material in the turbine.

The amount of material on the rack could clog the rack itself if the trash rack cleaning system has not been properly designed. This could lead to an increase of the head losses across the rack.

On the other hand, if the cleaning system has been designed properly a large amount of material should then be treated and sent to the dump with the related cost and operating problems.

Efficiency lack due to the type of sediment could occur when filamentous sediment such as grasses and algae are present in the water. In this case this sediment could pass through the trash rack and attach to the blades modifying its profile so that a consequently drop in the efficiency of the unit could be experienced.

In order to face these problems, it is suggested to perform a sediment transportation evaluation and characterization during design stage also for small HPP in order to design proper trash disposal area. This information will also be crucial in the definition of the trash rack spacing and the design of the trash rack cleaning system. The installation of floating debris barrier could help in decreasing the load on the trash rack and on the cleaning system but not every plant design allows for that.

In order to face the efficiency reduction due to algae and modification of the blades profile, a frequent cleaning cycle of the turbine must be implemented in the plant automation.

From the case studies proposed the following lessons can be learnt regarding the civil and hydraulic design:

- *Sediment transport is a problem for low head hpp, causing clogging of rack and, consequently, head losses. Dedicated solution such as a proper design of the space between the rack bars according to the type of turbine must be envisaged in order to ensure the right balance between the clogging effect on the rack and the level of cleaning of the turbined water*
- *Despite the shallow considerations made, the quality of the water seems to affect the efficiency of the turbine for very small head. Presence of filamentous suspended material and formation of algae could modify the blades profile and, consequently the efficiency of the turbine.*
- *Plant located along polluted rivers are much more subject to efficiency problems due to formation of algae due to the higher concentration of organic material in the water.*

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