# Predictive maintenance in small hydro through condition monitoring: Opportunity and complexity

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## Introduction

The paper is focused on the predictive maintenance in small hydro and namely on the use of the condition monitoring to reduce the risks and the maintenance costs as well. The method provide in fact extensive information to target spending on more effective maintenance measures and works.

## 1. Risk based maintenance

The risk based maintenance is a method of planning the servicing of a facility taking into account the failure risk. It is widely implemented in hydropower, although it could be based on seemingly irreconcilable views, such as:

a) run to failure, that means operation till the next fault
b) maintenance based only on the current plant condition
c) preventive maintenance
d) predictive maintenance

Although preventive and predictive maintenance could seem based quite on the same idea, there is a slight but important difference. While the first method implement all the maintenance works generally advisable to avoid the failure, the last one try to foresee which works are really crucial for a reliable operation. In other words, the predictive maintenance has a saving potential, but its exploitation needs a better knowledge of the plant condition, not to take a too high risk.

The role of the condition monitoring is precisely to implement a continuous plant assessment in order to improve the risks assessment while reducing, as much as possible, the maintenance costs. In any case, the cost of the implementation of the system must be shortly paid back through either the reduction of the O&M costs or the raise of the revenues coming from an increased mean annual production.

## 2. Predictive maintenance in small hydro

A more selective and effective servicing is indeed the present challenge in hydropower, particularly in Europe, considering the current low spot market prices. Small hydro has though some particularities also with regard to this topic.

On the one hand the mere reduction of the insurance premiums could be so significant to sometimes cover the entire costs of the monitoring. The owner of a small hydropower plant could spend for the insurances up to the 15% of the entire expenditure for the O&M and a better evaluation and frequent check of the maintenance conditions and of the risks could allow for the reduction of the insurance premiums or, in some cases, of the extension of the covered risks.

On the other hand the high costs of complex expert systems could be incompatible with the plant size. The implementation of the condition monitoring and of the predictive maintenance could be even more cost intensive if the client owns just a single HPP, which is not infrequent in small hydro.

If we consider, in addition to that, the difficulty to monetize the benefits of the method, strongly affected by the lack of historical data for small plants, so as to convince the owner to finance the implementation of the system, it´s not surprising that the predictive maintenance is still a pioneering matter in small hydro. The interest seems however to be growing rapidly at the moment, if we consider that our Company alone has got three orders in the last few months for the design of a digital monitoring system.

It is particularly important in this context to design a tailor-made solution, at best with a step by step implementation process, with low initial costs and the possibility to extend the system once the owner has experimented the pros of the predictive maintenance.

## 3. Monitoring implementation

As the implementation process of the monitoring is concerned, we divided the activities in the following six main stages. It is our classification, of course other partitions are possible as well. The following scheme represents graphically the overall process:

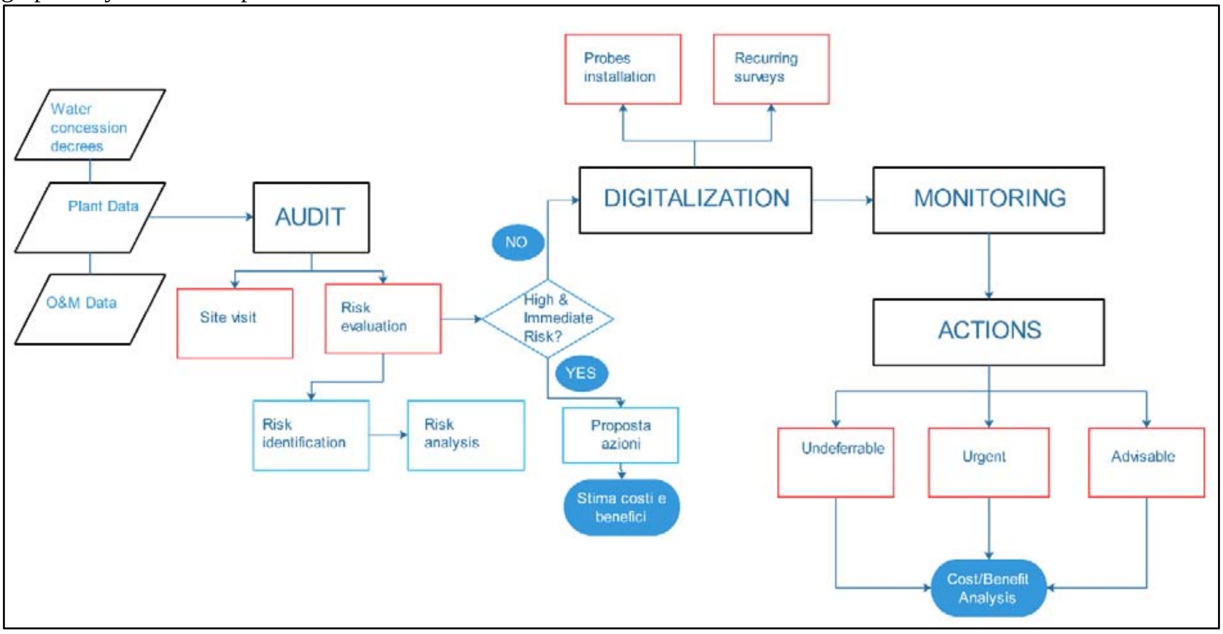


*Fig. 1. General monitoring scheme*

### 3.1 Plant audit

The assessment of the current plant condition is the first step, and it is based on the accurate observation of every part of the plant, on simple operation tests and on the check of the parameters already measured on site, such as temperatures and vibration. If historical series of some parameters are available, their trends provide a very useful information.
Last but not least, a historical research should be carried on, collecting information from the powerhouse records and from the local staff, including unavailability time, list of problems, failures and events, list of the available spare parts, O&M program and so on.
The local staff had traditionally a long-time (almost personal) relation with the hydropower plant and were custodians of the plant memory, that means a huge amount of valuable information. Although it is in some cases still true, particularly in small companies, the current trend is mainly different: companies that own many hydropower plants tend to employ a bigger team that take care of the whole asset or of a branch, while small companies tend to externalize the O&M. In both cases, the implementation of the monitoring system could be also helpful as a substitute for the former human memory.

### 3.2 Identification of the risks

With all the collected information it is now possible to identify all the risks connected to the condition of every plant component, from the point of view of both the safety and the operation continuity.
Besides that, the plant operation have to fulfil all the requirements of the water concession and/or the building permits, otherwise the consequence could be a heavy fine or, in the worst case scenario, the temporary or permanent withdrawal of the licences.

| *Type of risk* | *Part of the plant exposed* | *Examples* |
|---|---|---|
| *hydraulic (water)* | dam/weir, intake, diversion channel/tunnel, turbines | flood, cavitation |
| *hydraulic (oil)* | hoists, hydraulic equipment | defect, insufficiency |
| *geotechnical* | every civil work, indirectly also the machines (e.g. loss of the correct alignment) | landslide, (differential) settlement |
| *structural* | every part, directly or indirectly (damage due to the collapse of a part) | collapse, excessive displacement |
| *mechanical* | electromechanical and hydromechanical equipment | collapse, excessive displacement, loss of the alignment |
| *electrical* | electrical equipment | breakdown of supply, fault, short circuit |
| *automation* | every part | breakdown (partial or complete), temporary or irreversible loss of control, configuration loss, wrong operation |
| *operation* | every part | human error, violation of company procedures |
| *security* | every part | unauthorised entry (physical or virtual) |

*Table 1. Type of risks.*

A mere identification of the risks doesn´t give enough information to design the monitoring system: it is necessary to evaluate also the probability of every identified event, based on the current plant condition, and the severity of the damage that this event cold cause either to the property (also in term of loss of production) or to the staff or to a third party.
It is useful to classify both the probability of the event (R) and the severity of the damage (D) into levels and to represent every level with a numerical growing value. The product (P) of these values give us a first identification of the most critical risks, which have to be taken into account in the next steps.
The classification should be as objective as possible, to assure a real picture of the severity of the problem through the parameter *P*, but we are not so naïve to trust completely the numerical representation and avoid an additional scrupulous analysis of every risks.
In any case, we have chosen a widespread classification, but we adapted it slightly to the case of small hydro. The result is shown in the *Table 1*.

| *Probability* | *R* | *Damage* | *D* | $P = R \cdot D$ |
|---|---|---|---|---|
| highly probable | 4 | extremely serious | 4 | > 8 |
| plausible | 3 | serious | 3 | 5-8 |
| unlikely | 2 | medium | 2 | 3-4 |
| improbable | 1 | low | 1 | 1-2 |

*Table 2. Risk analysis and risk management.*

There are three way to manage risks with growing severity:
- no measure needed (*P* up to 2);
- a risk management measure (*P* between 5 and 8);
- an urgent measure (either a maintenance works or a modification of the operation, according to the kind of risk) to remove or reduce the risk (*P* higher than 8).

As already said, the value of the parameter P is just a first indication: in particular, the eventual risk management measure should be evaluated from case to case for values of P between 3 and 4.
The risk is normally managed through the monitoring system described as follow, unless an operating or administrative measure is advisable, for instance an extension of the insurance coverage.

### 3.3 Identification of the parameters to monitor

Once the risks are carefully evaluated, we could review again the ones that need to be managed. The perspective is now different: our aim is to find out a possible parameter that could help us to forecast the possible failures.

If the bearings should be a critical part of the plant, according to the current maintenance condition, their temperatures and vibration are normally an important health indicator. In case of stability and durability of a civil structure the monitoring of the displacement could be useful.
Information about the frequency of a movement cycle are often significant, not only to foresee the duration of a part, but also because sometimes a too high frequency shows an inefficient automation logics. It is impossible of course to mention here all the parameters that could be taken into account in the design of the monitoring of a hydropower plant: the type and number of aspects involved are so various and most of them are strongly site specific.

### 3.4 Implementation of the monitoring system

The realization of the monitoring system is the core of the method, and consist of the design and the installation of different kind of sensors and the implementation of both hardware and software needed to acquire, store and check the identified parameters. The possibility to remotely check and download the data is an important plus, that allows access to the information both for the central internal staff and for external (but strictly selected) consultants. The access should be of course regulated and protected by a firewall and only few persons should be admitted. Moreover the access to the monitoring system should be separated (at best physically separated) from the access to the control system of the powerplant.

The design approach must have to take into account not only the technical aspects, but also the economical ones. As already highlighted in the § 2, the money to invest in a monitoring system is tight for a small hydropower plant and we should use the first round of implementation to prove the convenience of the system. Instead of designing a perfect system, we should make the effort to focus the proposal only on the key elements for the SHP reliability. By the way, not every parameter and information could be digitally monitored, and it is not always the most convenient way to check a risk: it is unusual true for the monitoring of an extended part, such as a many-kilometres-long channel or a tunnel. In this case, a periodical visual control is the best solution.

The common part of the system should be in any case easily expandable without high costs.

### 3.5 Check of the parameters trend

One of the biggest advantage of a monitoring system, is not only the availability of an high number of data, but also the possibility to check the historical trend of the parameters and to compare the current values with the ones of six months or many years older. In many cases it is much more interesting to know if a parameter is growing or decreasing than its mere magnitude. A higher mechanical vibration at the bearing doesn't mean necessarily that the unit needs an urgent service, although it is surely a warning to seriously take into account. It could be possible that the problem has been present since the very beginning, caused for example by not perfect hydraulic conditions that are not easy to change (a high NPSH, the shape of the inlet chamber and so on). It shows that there is room for improvement, but it´s something different from a serious urgent problem which could lead to a default. The increase of the vibrations in the same hydraulic conditions give us in that regards additional information.

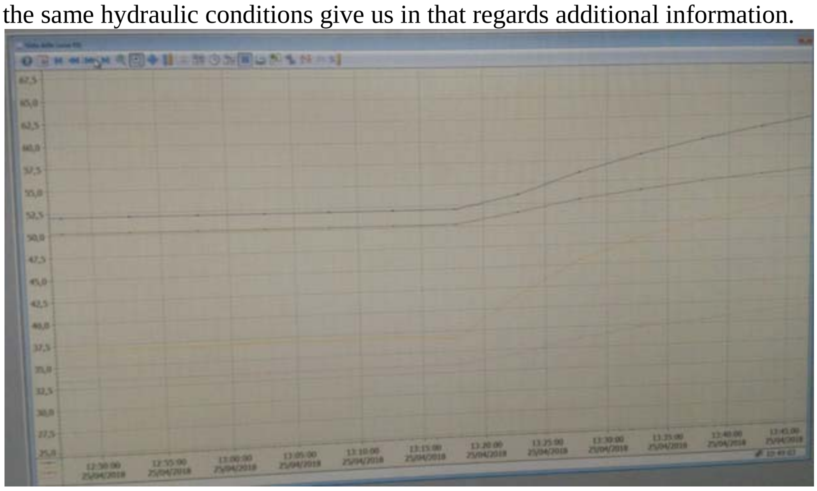

*Fig. 2. Typical trend of  bearings temperature*

The frequency of the check depends on the type of parameters and could take place monthly as well as once a year, but generally we suggest not to wait longer than six months. A first more frequent check could be in case performed by the internal staff, who could submit potentially critical aspects to a specialized consultant.
The frequency of the data recording plays also an important role: it should be high enough to allow to describe the evolution of a given parameter in different operational condition, but not too high: a huge amount of data could discourage the supervision or make the data elaboration and interpretation more difficult.
The result of the check of the parameters is a report in which all the trends are shown and commented. The conclusion of the report could be:

- positive: nothing to do till the next check;
- dubious: an expansion of the system or further investigation are suggested
- critical: a measure or a maintenance work is suggested (see the next paragraph).

**3.6 Maintenance program**

As said in the § 1, the purpose of the monitoring system is to focus the maintenance program on the works and measures aimed to reduce or prevent the main risks. The extensive information provided by the method allows us to identify more clearly the risks and to list them in the priority order. Furthermore we can identify the parts of the plant that shows the faster decadence process.
This helps not only to target the service program, but also to storage the mere spare parts that could be reasonably critical in the present plant condition, that we know quite precisely through the monitoring system.

## 4. Conclusion

The condition monitoring provides extensive information to target spending on more effective maintenance measures and works, that is absolutely necessary in the current economic conditions. In fact the current low spot market prices of the electricity press down the share of expenditure available for O&M.
In the worst case, even if the proposed works wouldn't be carried on, we know more clearly the risks that the HPP could be exposed to.
A frequently updated knowledge of the plant condition allow furthermore to regularly check the residual value of the asset, that plays an important role in the balance of the Company.


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