Assessment of the state of conservation, efficiency, and functioning of the hydropower plant’s components

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1 Introduction

At the end of the hydroelectric concession agreements of the large hydropower plants located in Trentino, in northern Italy, the outgoing concessionaires were asked according to the Provincial law, to assess the state of conservation, efficiency and functioning of the hydropower plant’s components. Given the number of the power plants to be assessed, more than one specialist’s work is requested, it therefore arose the problem to find a unique and shared method to proceed with.

To make this method objective and replicable as much as possible, it was based on a numerical approach through the quantification of different parameters. Furthermore, it was designed to be independent from the specialist who carries the plant’s inspection out. The model had to be based on parameters that could be collected from all the power plants; consequently, some measure detected by sensors that were installed only in few plants weren’t considered as evaluation parameters, otherwise it would have been impossible to compare the numerical results from all the plants and the plant assessment evaluation would have not been clear. The model had been already applied to more than 30 hydropower plants in northern Italy and had been presented as an official certified document to provincial institutions.

The lack of detailed information about the plant operation life and the impossibility to stop the plant to collect useful data, have led to the need to introduce indirect indicators for the evaluation of the components’ state.

As could be found in the following chapters, the adopted model has tried to keep separated the three elements mentioned in the Provincial Law i.e.: conservation, efficiency, and functioning, despite the clear links between them.

The power plants components had been classified in 20 categories according to their type or behavior.

Considering that the large dams must be assessed every year by the delegate engineer according to the same criteria as asked in end of the concession law (conservation, efficiency and functioning), the study presented was focused on all the components excluding the dams, whose assessment were deferred to that carried out annually by the engineer in charge. The numeric evaluation generates dispersed and discretized results and therefore not easily appreciable. To make the assessment clearer and more intuitive, some qualitative judgment categories corresponding to quantitative score ranges of the numerical method were created.

2 Procedure

The steps of the judging model applied to the plant’s components can be summarized as follow:

1. Definition of plant’s components
2. Definition of the components state of conservation, efficiency and functioning by answering the questions: What is the component conservation status? What is the efficiency status? What is the functioning status?
3. Definition, for each component, of the parameters adopted for the evaluation by answering the questions: what parameters should be used to evaluate the state of conservation? E.g. component efficiency? How does it work?
4. Definition of an evaluation rate of each parameter for every single component
5. Definition of a relevance scale (weight) of each parameter used for the component evaluation
6. Assignment of a qualitative membership class to the quantitative numerical evaluation related to each component
7. Definition of transition thresholds between one qualitative class and another

The developed model inevitably shows some stretches deriving from the choice to keep the assessments relating to the three elements - state of conservation, efficiency and functioning - strictly separated even though, by their nature, they are strongly interconnected. In the following pages, all the evaluation process stages, included the mentioned evaluation parameters forcing, are presented.

3 Definition on plant’s component and division in classes

Due to the fact that the nature of the plant components whose state of conservation, efficiency and functioning is to be assessed, is not defined in the provincial law, a partition of the plant into macro-components was performed. This partition is in accordance with the inventory document requested at the outgoing concessionaires. Such document splits the plant into functional components, usually in a number whose range varies from several dozens to few hundreds.
For an easy management of the judgments, it was decided to divide these components into different categories according to their technical-functional behavior (shown in the *Table 1*).
The evaluations were based on: considerations derived from the site inspections, documents shared by the plant concessionaire (like technical drawings, periodical inspection carried out by the plant’s operators, technical analyses, maintenance reports, replacement or installation reports and others) and the lists of measurements and alarms recorded by Scada. As introduced in the first chapter, the goal of this work is to produce a powerplant components assessment which, integrating the lack of the law dedicate guideline, produces judgments whose logical assignment path is retraceable and reproducible. Having to assign evaluation to dozens of power plants, the model should allow their comparison and hence there is a need to use the same judgment indicators to be applied to all the components. Therefore, special measurements or sensors applied only on part of the components are not used. These could increase or decrease their evaluation with respect to others where the same tests were not performed. The score attributed to each evaluation parameter of the single component varies between 0 and 100, where 100 represents the ideal condition with no deviation from the new.
For each parameter it has been assigned a relevance number named *weight*, also variable between 0 and 100. The meaning of this number is detailed in the following chapters. The parameters that do not evidence deviation from the optimum or whose defects or decay in operation are not expressly documented, are rated at a score of 100.

4 State of conservation

4.1 General indications

The state of conservation summarizes the effect of time on components. Its evaluation is referred to the time when the site inspection by Frosio Next took place. The effect of time can be assumed by answering the questions:

- how much the plant’s component, at the current state, differs from how it was originally?
- how much would it cost to restore the original condition of the component?

In order to be able to define the current conservation state of an object with respect to its starting state, a large amount of information should be available. For a mechanical component, for example, it would be necessary to know the material whereby each of its elements are made, the couplings between the various elements, the history of the mechanical and thermal stresses that affects the components; all such information has to be taken in account together with the microstructural analyzes performed to detect the variations of the physical component material state such as cracks, internal stresses or micro-deformations.
The direct collection of this information for each component would be in terms of effort and cost of the activity of disproportionate to the goal to be achieved, and, above all, incompatible from a chronological point of view. Consequently, an assignment of judgments values, based on parameters or physical quantities that indirectly provide information on the state of conservation, has been opted. These parameters are different depending on the category to which the component under examination belongs to in fact, they can be operating parameters, degradation, or aesthetics.
As far as the assessment of the state of conservation is concerned, the age of the component is introduced as a further indirect parameter. It does not generally indicate directly how much an element deviates from its initial condition: it may have been subjected to maintenance or care that has kept it in the best way even if it is old, or, vice versa, even if it is very recent or it could have undergone to stresses that degrades it in a very short time. Concerning the age judgement, the average life expectation is taken as a reliable reference derived from specialistic literature; specifically, it is considered in one of the most authoritative publications in the sector, “Wasserkraftanlangen. Planung, Bau und Betrieb” – Springer 1997-2009 written by Jurgen Giesecke and Emil Mosonyi.
In case some components have been subject to an extraordinary maintenance (i.e., operations of revamping, or replacement of some of their essential parts), it has been considered a partial "recovery of technical life" proportional to the extent to which the modification affects the initial condition restoration.
It has been attributed a low evaluation on age (indicatively 10 out of 100) but not zero for all components that, despite having exceeded the expectation life threshold from literature, are still in function and in use. The weighted average of the values assigned to the various indirect parameters defines the state of conservation of the component.

		Homogeneous component "X"
Parameter's weight	State of conservation parameters	81,6
32	Parameter 1	100
28	Parameter 2	80
20	Parameter 3	100
8	Parameter 4	60
12	Parameter 5	20

State of conservation of the homogeneous component "X"; weighted average of his parameters

Relevance of every parameter on the state of conservation of the "X" component, out of 100

Parameter value respect to new, out of 100

***Fig. 1**: State of conservation of the homogeneous "X" component*

The state of conservation of a complex component, composed by several sub-components of different nature (civil, electrical and mechanical structures), is more difficult to evaluate. Then it has been decided to split those components into homogeneous sub-components.
For each sub-component it has been assigned, as done for the parameters, a weight indicating how much its own state of conservation is relevant on the state of conservation of the complex component.
For example, the category C3 includes hydraulic intake structures that are composed by civil works, mechanical items and electromechanical components. All these sub-components cannot have the same evaluation parameters regarding their state of conservation, it is therefore opted to "split" the judgment of the overall component state of conservation into the judgment of its own "homogeneous" parts. The sub-components have different weights, depending on how much their restoration contribute to the main item restoration. Therefore, the overall conservation state of the component is calculated by taking the weighted average of the conservation states of its sub-components.

		Dis-homogeneous component "Y"				"Y" state of conservation weighted average
						72,9
		Homogeneous sub-component 1	Homogeneous sub-component 2	Homogeneous sub-component 3	Homogeneous sub-component 4	
Parameter weight	Parameter	45	5	20	30	Sub-component weight
25	Parameter 1	60		100		
20	Parameter 2	100			90	
14	Parameter 3		40	10		
6	Parameter 4	70		50	90	
9	Parameter 5		80	80		
11	Parameter 6		100		100	
15	Parameter 7	30	20		80	
Sub-component state of conservation		66,2	54,7	67,8	89,2	

Value of the parameter compared to the new, out of 100

State of conservation of the component "Y"; weighted average of his sub-components state of conservations

Weight, or relevance, of the homogeneous sub-component on the dis-homogeneous compoenent "Y"

Parameter weight on the sub-component's state of conservation, out of 100

State of conservation of the sub-component: weighted average of the parameters that describe it

***Fig. 2**: State of conservation of the dis-homogeneous "Y" component*

4.2 State of conservation evaluation parameters

Depending on the nature of the object which the conservation state is being evaluated for, different parameters need to be considered. However, the age is always considered for all objects, regardless of their specific nature. For civil structures, the indicators of the conservation state are exterior damages that can be identified through visual inspections of the item itself, such as structural cracks, exposed reinforcement bars, water infiltrations, etc. This choice is motivated by the fact that, in most cases, there are not operating parameters available that can be considered as indirect indicators of the conservation state, at least, among the common measurement that can be taken without sensors installations and their monitoring.
On the other hand, for electromechanical systems, and especially for rotating machines, there are identifiable operating parameters that can indicate, even indirectly, the conservation state. An example of such parameter is the temperature of the turbine supports. A high temperature of the supports, in addition to the evidence that such occurrence is potentially caused by an insufficient cooling and lubrication systems, can be an indirect indicator of various mechanical problems. However, there are also parameters that are not easily measurable or do not have absolutes values, such as noise. It is expected that a worn-out or defective machine will be noisier compared to one in excellent conservation state. When it comes to electrical and electronic works, assessing the conservation state becomes even more challenging. Visual inspections, whether during Frosio Next site inspection or periodic plant’s personnel checks, can only provide limited information about the conservation

state. For this type of components, the indicators considered, in addition to age, include the presence of oxidation on terminals, the dirt in panels and the integrity of components. In the following table the indirect and, when possible, direct parameters that best describe the conservation state of each component class are shown.

CAT	COMPONENT	PARAMETERS	WEIGHT
C1	Screen, gates, valves	Anomalous deformations	24
		Structural cracks	20
		Cracking	13
		Rust	7
		Coating peeling	1
		Age	35
C2	Tunnels (including adits), channels, surge shafts, tale race channels	Structural cracks	24
		Exposed reinforcing bars	20
		Plaster/coating cracks	5
		Rust	7
		Water infiltr./leaking	8
		Vegetation/dirt	1
		Age	35
C3	Intake structures, weir, basins	Structural cracks	18
		Exposed reinforcing bars	12
		Plaster cracks	4
		Water leaking	2
		Weir undermining	6
		Rust	3
		Sealing deterioration	8
		Actuators integrity	6
		Paint peeling	1
		Shield deterioration	12
		Excessive deformations	12
		Age	16
C4	Penstocks and their protection systems, including valve chamber access, supply pipeline	Water loss	20
		Anomalous noise	10
		Structural cracks	10
		Plaster cracks	2
		Rust	7
		Paint peeling	1
		Excessive deformations	20
		Age	30
C5	Turbine and pumping systems	Bearings T°	10
		Bearings vibrations	10
		Anomalous noise	10
		Oil leaking	5
		Water leaking	4
		Pipeline wear	5
		Rust	4
		Turbine efficiency	10
		Bended carter	6
		Specialistic inspect. freq.	6
		Age	30
C6	Generator units	Stator wiring T°	16
		Bearing vibrations	16
		Anomalous noise	10
		Current fluctuation	7
		Oil leaking	6
		Water leaking	3
		Rust	2
		Specialistic inspect. freq.	8
		Age	32
C7	Transformer units and distribution line up to switchyard	Wiring T°	12
		Nucleus T°	12
		Isolation	12
		Anomalous noise	10
		Current fluctuation	7
		Oil leaking	4
		Deformations	3
		Rust	2
		Specialistic inspect. freq.	6
		Age	32
C8	Medium voltages connections, high voltages substations	Connections integrity	14
		Isolators integrity	14
		Carter integrity	6
		Supports integrity	6
		Specialistic inspect. freq.	10
		Age	50
C10	Balance of Plant (BoP) systems and others power-house systems	Control panel integrity	15
		Exposed/burned cables	23
		Oxidized terminal block	20
		General cleaning	12
		Carter integrity	2
		Services (AS)	2
		Room cleaning	1
		Age	25
C11	Emergency power supply systems (UPS)	Structure integrity	25
		Rust	22
		Oil/gasoline leaking	15
		Painting peeling	3
		Specialistic inspect. freq.	10
		Age	25
C12	Plant’s control and supervision systems	Control panel integrity	14
		Exposed/burned cables	18
		Oxidized terminal block	18
		General cleaning	10
		Age	40
C13	Cooling systems, dewatering and water systems	Water leaking	14
		Pump noise	16
		Pipeline oxidation	16
		General cleaning	9
		Age	45
C14	Overhead cranes and others	Cables damages	20
		Rust	18
		Guides damages	16
		Control panel integrity	7
		Painting	7
		Age	32
C15	Buildings	Structural cracks	25
		Exposed reinforcing bars	22
		Plaster cracks	10
		Rust	6
		Water infiltr./leaking	8
		Vegetation/dirt	1
		Age	28
C17	Spillways from hydraulic structures	Structure stability	30
		Water leaking	20
		Pipes deformation	10
		Rust	5
		Age	35
C18	Bridges and other civil infrastructures for exclusive use	Structural cracks	25
		Exposed reinforcing bars	22
		Plaster cracks	10
		Rust	6
		Water infiltr./leaking	8
		Vegetation/dirt	1
		Age	28
C19	Cableways, elevators, and penstock	Mechanical integrity	25
		Rust	18
		Electrical integrity	17
		Railway/guide integrity	7

	transportation trolleys	Protections integrity	3
		Age	30
C20	Fire-Fighting systems	Leaking	25
		Rust	18
		Cracks	17
		Water infiltr./leaking	7
		Vegetation/dirt	3
		Age	30

Table 1: *Parameters for the state of conservation of every component's category with their respective weight*

4.3 Note on the scoring judgment associated with the state of conservation

Some specific cases of scoring are analyzed and the score judgment procedures are defined to make the results as objective and replicable as possible. An example is reported below:
It is decided to not consider the number of start and stop cycles of an electromechanical component as a conservation parameter even though it affects its condition. This for the following reasons:

- it is not known what number of start and stop cycles the useful life of electromechanical components taken from literature and used as a reference refers to; therefore, it is difficult to establish the threshold from which the number of cycles can increase or reduce the state of conservation;
- while it is not directly included in the indicators, the number of starts may have effects on other parameters involved in the assessment of the state of conservation and so, indirectly, affects its value anyway. For example, a high number of valve operations could lead to an anomalous noise.
- not all items have a relevant history or knowledge of the number of start and stop cycles, especially if they are installed in the 1940's or 1950's. In order to be objective, only parameters available for all the plants are considered.

5 State of efficiency

5.1 Methodological questions

For many of the components to be evaluated, define the efficiency is a very difficult task also because the concept of efficiency itself it is not defined in the provincial law 4/1998 of the autonomous province of Trento leaving therefore to the evaluator the freedom and the burden of this definition. For the specific purposes of this study, a component is efficient when it can perform its function in the best possible way. The concept of efficiency is borrowed from the physical concept, as a relationship between the real performance and a benchmark. A series of questions arise both on methodological and evaluation level:

1. Is it possible to define a real performance? *methodological question*
2. if question 1 can be positively answered, how is the reference service defined? *methodological question*
3. if questions 1 and 2 can be answered, are there information on the real performance? *Evaluation question*

For some objects the definition of real performance is simple. Turbine represents an example of component for which a clear efficiency assessment procedure is defined. The procedure is developed in full hereafter to illustrate the application of the method.

5.1.1 Example: the turbine

The function of the turbine is to transform the potential and kinetic energy of the water into mechanical energy based on a flow rate and an available head. Since perpetual motion is not possible, this transformation implies energy losses; therefore, taking up what was mentioned in the introduction, the efficiency of the turbine itself is the ratio between the output energy and the entrance energy in the machine. Question 1 has apparently found a solution. How can answer at question 2?
There is not a single answer since a reference depends on convention and varies on the purposes to obtain. For this study, the reference performance is assumed equal to the one of the hydraulically similar turbines with the best efficiency available on the market at the time of the commissioning. This choice led to additional difficulties; firstly, the collection of an amount of sufficient and precise information on the state of the art at the time of the starting service. Considering the margins of uncertainty and discretion which all evaluations in progress are affected by (starting from the assignment of the weight values to criteria), it is believed that the approximation adopted here is reasonable. Question 2 has apparently found a solution.
Question 3 could be further articulated by considering the following cases:

a) recent information on actual performance is available
b) there is no recent information on the actual performance
c) no information of any kind on actual performance is available

Case a): the evaluation is easy, and we proceed by calculating the efficiency as the ratio between actual performance and reference performance.
Case b): theoretically speaking, there should be a method to evaluate whether and how much the real performance changes over time; knowing such variation, it should be possible to transpose non-current information into current. It is a very difficult task. For instance, since there are turbines that work water full of very abrasive solid particles, such operating conditions cause a very quick decay (a few years) of the machine performance. Even though functioning information relevant to dozens of years is available, this information could not be used tout-court, but it would be necessary a method for the discounting of older results. In the studied case, in the light of the considerations made above on the general uncertainty of the evaluation method, it has been decided to strictly adopt the old information without make any corrections.

Case c): having to try to give an evaluation anyway, an efficiency value reference for the turbine equal to η_{turb} = 0.78 is assumed. Such values represent a caution evaluation for the hydroelectric park commitment, carried out on medium-large size of medium-high age powerplants subjected to careful maintenance and inspections.
The reasoning exposed for the turbines can be replicated, with necessary modifications, for generators, transformers, or similar machines.

5.1.2 Estimation of efficiency for components other than hydraulic and electric machines

For hydraulic and electric apparatus, efficiency is usually considered as the efficiency value that they perform compared to a reference efficiency; for all other components, the quantification of efficiency is not so immediate.
Maintaining the concept of efficiency connected to the optimal use of a resource, not all the components of this work have a direct or easy quantification of it. A couple of examples may clarify.
An intake structure has the purpose to canalize with continuity different flow rates up to the maximum design value, or at least the maximum flow rate established in the plant's water concession decree. Therefore, the efficiency of the intake structure can be evaluated as the ratio between the real derived flow and the maximum concession for that intake. However, whether neither the maximum intake flow rate nor the maximum from the concession decree is defined, there is no possibility of applying the definition made; this occurrence is often in the cases studied.
A very different example refers to the hydraulic control unit for the regulation organs of a turbine. In this case, the efficiency could be evaluated by comparing the energy consumed by the control unit with the best system available on the market at the time of commissioning. It must be said that the task is incompatible with the provincial law requirements that assumes the hydraulic system a sub-component of the turbine, so its efficiency weight on the overall efficiency of the turbine macro-component is so low that it does not affects the global rating.
Another different case, very recurrent in a hydroelectric plant, is that for many components there is also no way to evaluate their efficiency based on the definition recently given. Therefore, for all these components, the efficiency is conventionally set equal to the maximum, i.e., 100. Given the excessive randomness in the definition of efficiency for these components, it is implicitly chosen to use the other two elements: the state of conservation and functioning for the evaluation requested from the law.
The efficiency of heterogeneous components is again obtained as a weighted average of the efficiency of its components. In this case, the weight of each component is different from that used for the assessment of the state of conservation because the relevance of the component is no longer measured by its deviation from the new one, but by how much the component affects the ability of the main component to perform efficiently.

6 State of functioning

The evaluation of the state of functioning of the various power plant components follows the main criteria outlined above regardless of the category they belong to.
This method is partly taken from the FMEA (Failure Mode Effect Analysis) method. It foresees the assignment of increasing scale rates, ranging from 0 to 100, to define the state of functioning of each component and, in association with those rates a weight. These weight values are defined according to the relevance that each component has in terms of the global state of functioning. The criteria adopted for the components to evaluate are the following:

1. **Is it currently available?** [WEIGHT 20] Indicates whether, at the time of the inspection, the component was available for operation. This criterion provides first information about the functioning of the item.
2. **Hours or number of plant shutdowns caused by component malfunction** [WEIGHT 12] This criterion contains information relating to the operation of the component over time.
3. **Would be there an amazement if the component stopped working?** [WEIGHT 8] Indicates the perception of operating personnel on the functioning of the component. It considers the information about previous criterion (i.e. the annual number of blocks) and from personal impressions from the observation of the component.
4. **Availability of spare parts** [WEIGHT 8] A low value is assigned to all those components currently in operation for which, however, in the event of a breakdown, there is a lack of spare parts or of the abilities to fix them. It mainly refers to components like PLC or SCADA.
5. **Maintenance and controls performed** [WEIGHT 12] This criterion considers the routine maintenance and control activities on elements that are susceptible to malfunction due to poor periodic maintenance. It mainly refers to wear elements or to the movement of occasionally operated mobile parts. An item where quality is monitored is evaluated as functioning better than an unused and untested one.
6. **Malfunctions, problems, defects** [WEIGHT 16] Provide information about partial malfunctions or defects in progress that reduces the functioning of the component.

7. **Surrounding environmental conditions** [WEIGHT 6] Similarly to previous evaluation criteria, this criterion provides information about the risk of failure of the components over time. It is mainly referred to open-air structures as intake or canals. Examples could be a canal that crosses a landslide slope risk or an intake structure located in an area with a high falling rocks risk.
8. **Monitoring/controls frequency** [WEIGHT 8] This criterion considers the functional parameters checked through the monitoring system, which provides information about their operation. Better ratings are given by the items that are checked continuously and that include safety alarms.
9. **Relevance of monitoring/controls** [WEIGHT 10] This criterion is related to the previous one and indicates how much the checked parameters are complete for an exhaustive control of the functioning of the object.

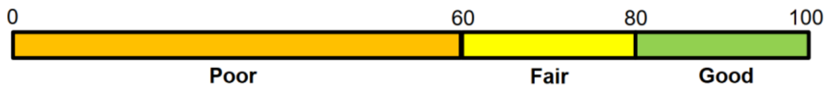
Once again, the functioning of complex components is obtained as the weighted average of the functioning of its components.

7 Qualitative judgement classes

The last step of the model associates with each numerical value of states of conservation, efficiency and functioning, a qualitative membership class. Such qualitative judgment is expressed by three classes: poor-fair-good. The purpose of this classification can be summarized as follows:

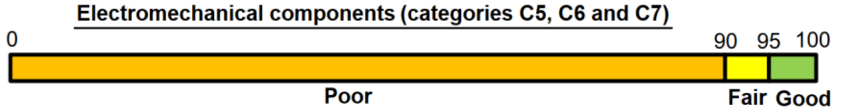
- to have a better perception of the different judgments assigned to the various components
- to avoid subdivision into a too wide number of classes in order to minimize both randomness and uncertainty of their scoring – matter described in the previous chapters –
- to allow a more immediate comparison between components
- numerical evaluations do not lead to an absolute ranking; frequently the parameter's evaluation and their weight provide score values from which is not possible to draw conclusions. On the other hand, the large number of evaluations carried out, whenever sorted in classes according to thresholds, allows to see similar conditions among the processed components.

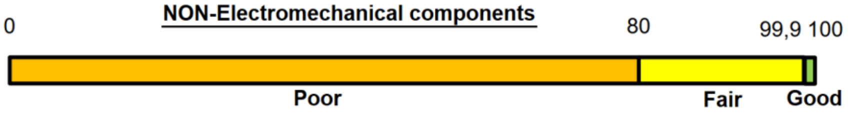
For this purpose, it is decided to adopt 3 qualitative classes for the assessments of each judgment parameters. The assumed thresholds discriminate numerical ratings in the quality judgment categories poor, fair and good. The poor category is associated with components with evaluation score lower than 60, the fair category is applied to components with scores between 60 and 80, while the good category is for components with scores above 80.



7.1 State of efficiency

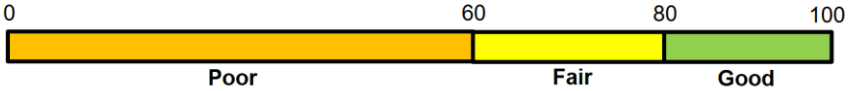
Similarly to what was done for the state of conservation, the thresholds discriminate the numerical efficiency evaluations in Poor, Fair and Good classes. Setting the thresholds to discriminate the judgment of the state of efficiency is as difficult as it was to define the efficiency of the various components.
Given the difficulty of define efficiency for a lot of different categories of components, like channels, intakes, and electrical infrastructures, the value of their efficiency is frequently 100. The quantitative assessment of their efficiency has become, as a matter of fact, a qualitative assessment, in which the deviation from the excellent (100) is assigned to all those works where a loss of performance is evident.
For this reason, it is decided to place the threshold between fair and good just below 100, at 99.9: a value associated with every item in which is noticed at least a minimum variation in the performances.
The threshold for the transitions between fair and poor is fixed at 80.
For electromechanical components, typically belonging to categories C5, C6 and C7 the evaluation is simpler since performance is easily measurable. In this case, an assignment of value could assume a quantitative character. The threshold at which the judgment passes from the best to the one below is equal to 95. It could appear a high score but just consider that the reduction of turbine efficiency in the range of 5% with respect to the best turbine possible is considered a huge reduction. Following the same reasoning the lower threshold is fixed at 90.





7.2 State of functioning

The thresholds discriminate numerical evaluations of the functioning state in the following qualitative judgments: Poor, Fair and Good.
The Poor judgment category includes, among others, all the works whose functioning presents obvious problems. The upper limit threshold belonging to this category is 60. As illustrated in chapter 6, the functioning status is calculated through 9 judgments of a more qualitative than quantitative nature ("will be there surprise if the component stopped working?" or "is currently available"). The definition of the judgment attribution thresholds, in the same way, arises from the application of a more qualitative rather than quantitative method, based on the number of positive/negative scores. Given that the average weight of the questions is around 10, it is decided to fix the poor judgment to all the works with a score lower than 60, corresponding to at least 4 negative judgment scores. The Good category is the one whose works have the maximum score. The lower threshold limit of the good category is set at 80 corresponding indicatively to two negative outcomes of the parameters that define the functioning score. The Fair category collects intermediate judgments between 60 and 80. Regarding functioning it must be said that components with Fair and Good judgements have to be considered "in regular operation".



8 Possible implementations

The time schedule of the assessment is given by the law obligation; with more time to dedicate at it would be possible to implement the model with the introduction of direct parameters, such as measurements from new installed sensors. Another challenging goal may be to monitor numerical judgements and parameters over time in order to plan maintenance and replacement interventions.

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