MAINTENANCE STRATEGIES APPLIED IN HIDROELECTRICA

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Abstract - The paper contains a synthesis of the maintenance strategies applied to hydropower equipment and installations within the power plants in Romania. The application of optimal maintenance strategies will become increasingly important in order to ensure the greatest possible power and energy availability by hydroelectric power plants in the context of the gradual abandonment of energy sources from hydrocarbons.

Keywords: maintenance, preventive, corrective, strategies, hydropower plants.

1. INTRODUCTION

Energy is a vital requirement of human beings and plays an important role in the development of every country.

The development of renewable energy sources (hydro energy, wind energy, solar energy, biomass, geothermal energy, wave energy and the use of hydrogen), as a significant and non-polluting energy resource, is one of the main objectives of world energy policies and they aim to protect the environment and commercial-scale development of viable energy technologies.

Through the European Green Deal, three fundamental objectives regarding the field of energy were established: ensuring clean energy, accessible and safe energy, decarbonization of the energy sector and the EU becoming the world leader in the use of renewable energy resources and energy efficiency [1].

Hydro energy has a share of approximately 17% of world energy [2]. In the current conditions where energy resources are limited, it is necessary to adopt some processes to ensure their optimal management. The efficient use and valorization of hydropower resources can be achieved by: avoiding energy losses through water discharges, reducing the idle time of hydro aggregates (HA) by adopting automatic processes that ensure faster HA start-up times and ensuring availability optimality of hydroelectric power plants (HPP).

The energy produced by HPP ensures [3]:

- Energy for the "Centralized Market of Bilateral Contracts";
- Energy for the "Market for the Next Day";
- System services (reserve for frequency stabilization, reserve for frequency restoration with automatic activation, replacement reserve, defense The National Energy System (NES), restoration NES).

Ensuring optimal availability of a HPP can be achieved, for example, by operationalizing maintenance works, modernizing installations and adopting an optimal degree of their automation.

The modernization of HPP ensures:

- Improved efficiency of turbines and hydro generators (HG);
- Optimum operating mode of the turbines by correlating the opening of the wicket gate according to the water fall, including the correlation of the opening of the wicket gate with the opening of the turbine rotor blades at Kaplan;
- The rapidity of the automation processes in such a way as to reduce the energy losses during the idle operation of the HA;
- Optimum processes due to the possibility of measuring, monitoring and recording all the electrical and technological parameters specific to the installations;
- Realization of monitoring-diagnosis installations;
- Easy realization of the installations intended to ensure, as the case may be, the technological services of the system.

Hidroelectrica (HE) owns 187 HPPs, including pumping stations for the utilization of energy hydro input, with a total installed power of 6,641.9 MW [4]. The total installed power in the NES is 18,308,436 MW (situation on 21.09.2022) which represents 36.27% of the installed power in the NES [5]. The main activities carried out for the production of electricity in HPP are operation and maintenance (O&M).

2. SUMMARY OF MAINTENANCE STRATEGIES APPLICABLE TO HYDRO POWER PLANT

Adopting ineffective O&M strategies can lead to major technical and economic losses, such as unanticipated maintenance expenses and reduced revenue due to non-production of energy, such as unanticipated maintenance expenses and reduced revenue due to non-production of energy, while the lack of O&M strategies can affect facility safety including employee and public safety.

A strategy for objective planning of maintenance operations, estimating their costs and their execution, can be developed over time, based on analyzing the condition of the equipment. In case of hydroelectric equipment, maintenance can be: corrective, preventive or proactive, highlighted in figure 1 [6][7]. Corrective maintenance is carried out if an equipment/installation, during operation, accidentally breaks down. In this situation, the installation is put back into operation in a specific state of operation, which allows it to fully fulfill its functions - (curative maintenance) or put back into operation, provisionally, with full or partial fulfillment of its functions (maintenance palliative). Preventive maintenance can be: scheduled - when it is carried out according to a certain periodic or predictive planning - when it is carried out depending on the condition of the equipment. Proactive maintenance is carried out in order to eliminate the causes that generate equipment degradation. The method is based on the combined analysis of data related to the behavior in the operation of the equipment (analysis of the defects that appeared and the causes of their occurrence) and measurements specific to predictive maintenance.

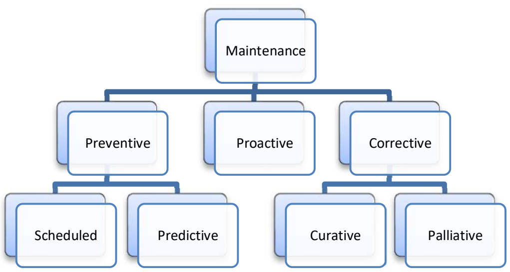

Fig. 1 – Types of hydropower equipment maintenance strategies.

The stages of carrying out scheduled preventive maintenance are illustrated in figure 2.

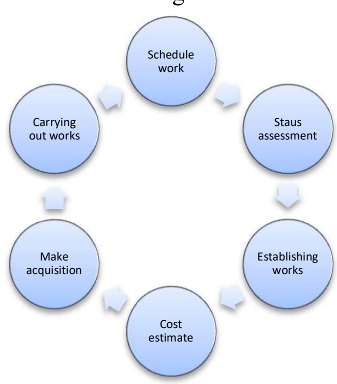

Fig. 2 – Stages of scheduled preventive maintenance.

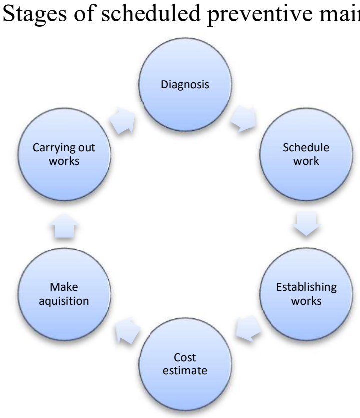

Fig. 3 – The stages of predictive maintenance.

As part of predictive maintenance (figure 3), the state of hydro equipment can be assessed both off-line and on-line. On-line is done with digital equipment installed at HA. Off-line is achieved by state measurements from the point of view of:

- Electrical: insulation resistance, ohmic resistance, air gap width, loss angle tangent (tg δ), switching times in switching equipment etc. [8];
- Mechanical: clearances in the bearings, alignment of the shaft turbine - generator, kinematics of the wicket gate, clearances between the blades of the turbine rotor and the spiral chamber of the turbine;
- Chemical: analysis of oil parameters in equipment etc.

Worldwide, the problems of reliability and maintenance of HA have been analyzed from various points of view, among which we mention [2]:

- Cavitation problems including turbine rotor blade cracks;
- The need to install monitoring systems;
- The need to install expert systems in order to adopt some maintenance strategies;
- Calculation of reliability indicators using models based on Markov chains;
- Development of preventive maintenance and calculation of reliability indicators (Weibull distribution) to determine the average uptime, failure rate and system reliability;
- Minimizing the number of failures and costs by applying the reliability-based maintenance criterion;
- Determining the level of risk in equipment according to their type (electrical vs. mechanical).

On-line monitoring of the HA status can be achieved by measuring: vibration parameters, air gap width, rotor operating parameters (winding temperatures, excitation current, vibrations), partial discharges (for HGs that have stator winding voltage higher than 10 kV), operating temperatures (in bearings, stator core and windings generator, cooling air).

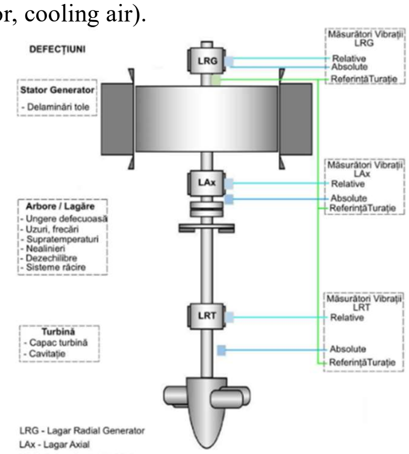

Fig. 4 – Vibration monitoring at HA [9].

For a correct diagnosis, absolute vibrations and relative vibrations must be measured at each bearing. Two transducers are required at each bearing, mounted at 90 degrees in the X and Y directions. And for a complete diagnosis, the absolute vibrations on the Z axes of each bearing will also be measured.

Air gap monitoring is usually done by means of 4 sensors mounted on the generator stator, positioned at 90 degrees: 2 sensors in the upper part and 2 sensors in the lower part of the HA, according to fig. 5. Monitoring the generator air gap allows determining: the geometric shape of the stator and rotor in the sensor mounting area, the relative position of the stator and rotor, the center of rotation of the rotor relative to the geometric center of the stator, the misalignment of the HA shaft. Usually, air gap monitoring at HG is required for rotors with large diameters where the expansions are large.

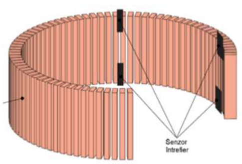

Fig. 5 – Installation of HG air gap sensors.

Partial discharge monitoring is performed on the stator windings when they are energized. Usually, the option of directional mounting of the capacitive couplers is adopted: three capacitive couplers at the active terminals of the HG and three couplers, at a distance from the terminals, towards the NES, according to fig. 6. This mounting option allows the filtering of noises coming from outside the HG, especially in the situation where the HG works together with a power transformer.

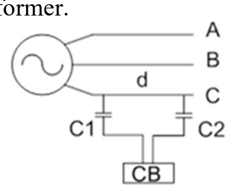

Fig. 6 - Directional mounting of transducers for measuring partial discharges.

The annual cost of O&M varies from 1% to 4% of the investment costs per kW, per year, and the IEA presented that the global average value is around 2.5% [2].

3. MAINTENANCE STRATEGIES APPLIED TO HYDRO ENERGY EQUIPMENT IN ROMANIA

In the hydropower field in Romania, scheduled preventive and corrective maintenance strategies have been adopted.

Along with the development of digital equipment, the monitoring of the operating status of the HA and from the point of view of vibrations began, but this activity did not bring significant changes in the planned maintenance programs. In the case of the existence of values in the zone of vibrations that are not allowed from the point of view of ISO standards, measures were taken to start the planned maintenance works earlier than the originally scheduled date. Excluding refurbished HAs, the planning of preventive maintenance intervals for HAs is done according to the number of hours of operation and for other electrical or hydromechanical installations, a periodicity is established through internal regulations. At re-engineered HAs, maintenance works are scheduled according to the technical condition that is given by the own monitoring-diagnosis systems.

In case of scheduled preventive maintenance, before and after the completion of the maintenance work, the condition of the HA is checked by: vibration measurements, checking the operation of the main technological protections, checking the functionality of the HA start-stop automation facility.

Within the maintenance activity, the provisions of ANRE Order no. 35/2002 which establishes the following categories of maintenance works [10]:

- Level 1 works (**LN1**). They are simple, low-volume works and operations, necessary to maintain some sub-assemblies and their component elements in an appropriate state from a technical point of view, in order to prevent premature wear, damage or accidents. Usually, these works are only meant to check the functional state of the components of an installation.
- Level 2 works (**LN2**). These works usually involve interrupting the operation of the installations, through partial dismantling in order to carry out repairs.
- Level 3 works (**LN3**). Works performed in order to restore the functional and reliability potential of the installations, for a period, at a level comparable to the initial one.
- Level 4 works (**LN 4**). They are complex works carried out on some installations which, without changing the initial technology, restore their technical condition and efficiency to a level close to the one at the beginning of their life.
- Corrective maintenance works (**MC**). They are works carried out on some installations accidentally damaged during operation and have the purpose of restoring the functions for which they were designed.

Analyzing the data of 2021 and 2022 regarding the commissioning of the CHE of Hidroelectrica, it is observed that the number of those who are 20-50 years old since commissioning has increased and the share of the newest ones has decreased, according to table 1 [4].

Table 1. Average age of CHE in Romania.

Average age a CHE	2021 [%]	2022 [%]
< 20 years	36,31	33,43
20 – 50 years	51,91	55,21
> 50 years	11,77 %	11,36 %

The main maintenance works carried out at CHE installations within the scheduled preventive works, type LN:

- To the turbine:
  - LN1: checking the functionality of sealing system, eliminating leaks in the water, oil and air circuits of the turbine's own installations;

- LN2: clearance checks in the bearing, revision of the turbine's own installations, replacement of defective equipment;
- LN3: all papers at LN 2 level and beyond: dismantling of oil-water coolers, removing the bearing and restoring the clearances, checking the clearances of the turbine blades in the spiral chamber, checking the clearances at blades wicket gate, checking the kinematics of the wicket gate, checking the actuation times when closing and opening wicket gate, restoring the alignment of the turbine-generator shaft.
- LN4: all papers at LN 3 level and beyond: removing the turbine rotor.

• To the HG:

- LN1: electrical condition measurements;
- LN2: revision of the generator's own installations, bearing clearance checks, air gap check, electrical protection functionality check, replacement of faulty equipment, to the electric cell through which the energy is discharged into the NES - insulation measurements of equipment in the cell, measurement of circuit breaker switching times.
- LN3: all papers at LN 2 level and beyond: disassembly of the exciter, disassembly of the bearings and restoration of the clearances in the bearings, checking of the condition of the pads of the bearing bearings, the condition of the windings, restoration of the alignment of the turbine-generator shaft, disassembly of the HG rotor – as the case may be.
- LN4: all papers at LN 3 level and beyond: HG rotor and stator removal for rewinding.

In 2005 and 2016, Hidroelectrica updated its own internal technical regulations regarding the maintenance activity considering the types of works (LN1, LN2, LN3, LN4 including MC) for different types of installations and equipment, according to tables 2 and 3[11][12].

Table 2. Operating hours of the HA for scheduled repairs - according to Norm 2005

Repair type	HA with Kaplan turbine	HA with Francis turbine	HA with Pelton turbine
LN2	2.500	2.500	3.000
LN3	10.000	6.000	14.000
LN4	40.000	30.000	48.000

Table 3. Operating hours of the HA for scheduled repairs - according to Norm 2016

Repair type	HA with Kaplan turbine	HA with Francis turbine	HA with Pelton turbine
LN2	6.000	6.000	4.000
LN3	24.000	24.000	16.000
LN4	60.000	60.000	40.000

The multi-annual operating average of an HA is 2,139.65 h/year. 24 HAs from Someș, Colibița, Drăgan-Iad and Crișul Repede hydroelectric development were analyzed. The power installed in HPPs from these hydroelectric development is 536.33 MW, taking into analysis only HPPs with an installed power greater than 3 MW. The on-line monitoring of the HA condition is carried out by monitoring the operating temperatures in the bearings, in the stator windings, cooling air at all HAs and the other on-line parameters, mentioned in the previous chapter, are carried out only at refurbished HAs.

In the period 2007-2022, the total number of incidents in HPP, which are owned by Hidroelectrica, is 6,853 incidents, with an annual average of 456.8 incidents, according to fig. 6. All these incidents generated accidental shutdowns of the HA, with unavailability of power, respectively energy not delivered according to the approved operating schedule.

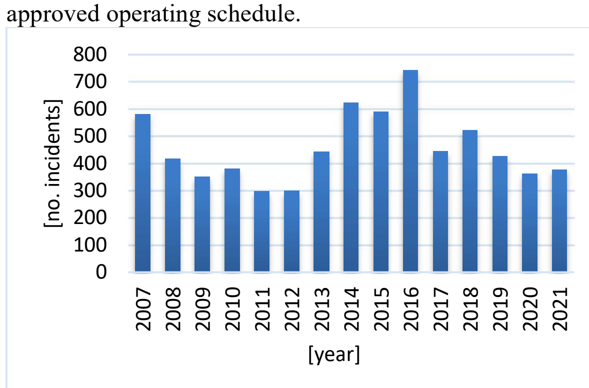

Fig. 7 – The evolution of incidents at HPP within HE.

The ratio between scheduled preventive maintenance works and corrective maintenance works, for example at HPP in Cluj Branch, is illustrated in figure 7.

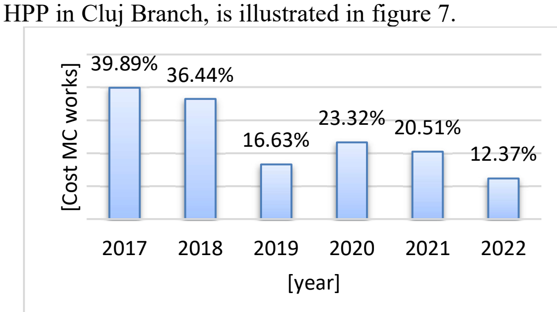

Fig. 8 – The share of the cost of MC works in relation to that of MPP works

Analyzing the incidents between 2007-2021, their main causes were: accidental shutdowns from protections and automations, shutdown in incident prevention, failure in reserve, operation with accidental power reduction and other causes, for example of an organizational nature. Most of the causes of the incidents were of an electrical nature.

The analysis of incidents in Hidroelectrica is based on NTE 004/05/00 and the information from the incident files are those established in Annex 3 of this regulation [13].

4.CONCLUSION

Hidroelectrica applies the following maintenance strategies:

- Scheduled preventive maintenance (SPM), for all equipment and installations;
- Corrective maintenance (CM), when accidental defects occur;
- Predictive maintenance (PRM) on equipment and installations monitored on-line or off-line.

The SPM and CM strategies are applied in accordance with the internal maintenance norm, on four levels of complexity (LN1 – LN4). In the past six years, it is found that the average share of the cost of CM works in relation with the cost of SPM works is 24.86%. Taking into account the advantages of predictive maintenance and the tendency to extend monitoring systems to power hydro aggregates, it is necessary to develop a specific rule for the ever more extensive application of this maintenance strategy within the Hidroelectrica company.

Taking into account the fact that maintenance strategies are based on operational reliability indicators, it is necessary to develop some technical norms specific to Hidroelectrica, their object being to establish the framework in which to carry out, from a technical point of view, the activity of registration, analysis and circulation of information regarding accidental events that take place in energy production facilities. In addition to the currently monitored quantities, it would be necessary, for the calculation of operational reliability indicators - the foundation for optimizing maintenance strategies - the highlighting of the values of other relevant random variables: the time of good operation of an equipment/facilities between two successive failures, how long the facility was unavailable etc. It would also be necessary to redistribute the categories of installations and quantify only the hydropower installations and those specific to the energy distribution activity and the thermal energy ones to be eliminated.

REFERENCES

1. European Commission. EC Documents: *European Green Deal.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
2. Krishna Kumar, R.P.Saini (2022). *A review on operation and maintenance of hydropower plants*, Sustainable Energy Technologies and Assessments, volume 49, February 2022, https://www-sciencedirect-com.am.e-nformation.ro/science/article/pii/S2213138821007189
3. ***www.opcom.ro
4. *** www.hidroelectrica.ro
5. *** www.traselectrica.ro
6. Felea I., Coroiu N. (2001). *Reliability and maintenance of electrical equipment,* Publishing house Editura Tehnică, Bucharest
7. Felea, Ioan (1995). *Reliability engineering in electric power,* Publishing house Editura Didactică și Pedagogică, Bucharest
8. *** PE 116/94 (1996). *Normative of tests and measurements for electrical equipment and installations*
9. *** NHE-09/2022 (2022). Internal technical norm Hidroelectrica S.A. *Monitoring and diagnosis of hydro aggregates and power transformers*
10. *** ANRE - Order no. 35/2002 (2002). *Management regulation and maintenance activity organization,* https://portal.anre.ro/PublicLists/Ordin
11. *** Internal technical norm Hidroelectrica S.A. *Normative for programming the maintenance activity in Hidroelectrica* (2005).
12. *** NHE 01/2016 (2016). Internal technical norm Hidroelectrica S.A. *Normative for programming the maintenance activity in Hidroelectrica*
13. *** NTE 004/05/00 (2005). ANRE Order no. 08/2005. *Normative for the analysis and record of accidental events in the production, transport and distribution facilities of electric and thermal energy* https://www.anre.ro/ro/legislatie/norme-tehnice/normative-tehnice-energetice-nte