P05

Refurbishment of Hydro Power Plants

JADRANKO SUDAREVIĆ
KONČAR – Inženjering za energetiku i transport d.d.
Croatia

SUMMARY

The paper describes main reasons for refurbishment of hydro power plants. There are two main reasons for revitalisation of a hydro power plant. The most frequent reasons are obsoleteness and worn out condition of the equipment and the possibility of a unit efficiency improvement.
The paper summarizes the most frequent works during refurbishment: civil engineering works, works on hydro mechanical and electromechanical equipment.
The refurbishment process is made of various activities. The approach to the refurbishment is different for each power plant resulting in a refurbishment process that differs in a certain degree from a power plant to a power plant.
The paper also describes possible refurbishment benefits such as improvement of the safe operation of the power plant, increase of reliability and availability of the equipment, increase of power and generation of electric energy, increase of the static and dynamic stability, decrease of generation costs, etc.
A special attention is paid to the process of refurbishment of the electric equipment, in the first line generators and excitation systems.
The paper describes several possible generators refurbishment variants, from replacement of individual parts, in the first line the stator and the rotor winding, to the complete replacement of all generators parts.
The paper considers possibilities of an increase of the power and the efficiency of refurbished and revitalised machines as well as some improvements bound to new technical solutions.
Benefits achieved by performed refurbishment and revitalisation of the equipment are described at the end as well.

KEYWORDS

Hydro power plant, refurbishment, generator, excitation system.

jadranko.sudarevic@koncar-ket.hr

INTRODUCTION

Construction of hydro power plants started at the end of the 19th century. The first power plant based on the principle of the alternate current invented by Nikola Tesla was put into operation on the Niagara Falls in 1881. Since the moment, the hydro power plant construction technology has been successfully spread all around the world and today hydro power plants generate about 15.8 % of the total global generation of the electric energy. The size of units has been gradually increased from starting small powers of a few kilowatts during the time to current powers of several hundred megawatts. Refurbishment of equipment enables a continuance of the generation of the electric power from the water potential by existing power plants in a safe manner at an acceptable investment. Investments into refurbishment of existing plants are significantly lower than investments into new hydro power plants since civil engineering facilities do not require any reinvestment and their value amounts up to 80 % of the investment into a new power plant.
Practically speaking, refurbishment comprises all the parts of a hydro power plant including civil engineering parts of the facility (dams, tunnels, power houses, input and output buildings, etc.), hydro-mechanical equipment and electric and mechanical equipment.

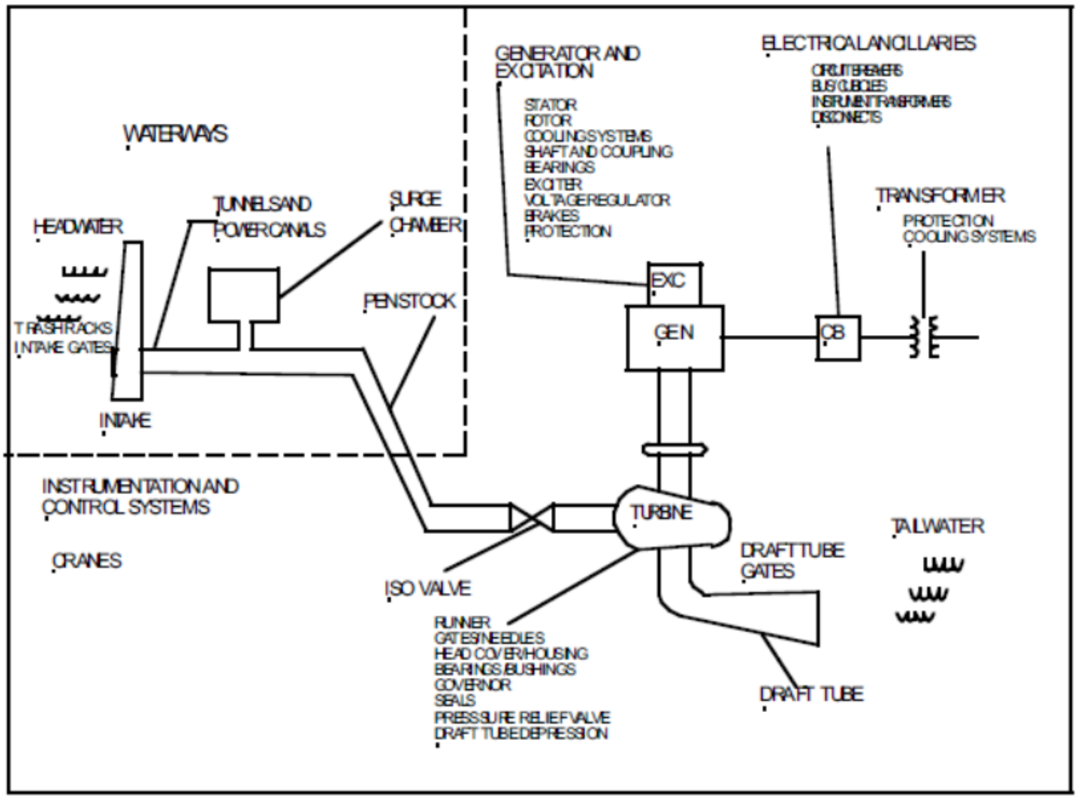

Figure 1 Typical hydroelectric power plant systems [1]

MAIN REASONS FOR HYDRO POWER PLANT REFURBISHMENT

There is a range of reasons to refurbish a hydro power plant. The most frequent are obsoleteness and worn out condition of the equipment resulting in a gradual decrease of generation of the electric power during years and in a lowered profitability of the hydro power plant.
Refurbishment of a hydro power plant and its equipment should be considered in following situations: when the availability of units is decreased, if there is a possibility to return the equipment performance to the initial ones or to improve them, when significant changes of

plant operating conditions or operating units have been faced, if there is a possibility to automate the plant, when the operating capacity of the plant is decreased, if large failures of the main equipment are faced requiring large investments, when the plant of the equipment cannot stand possible earthquakes, when spare parts are not available any more, if the equipment maintenance cost is significantly increased and plant operating cost are high or if the operational safety of the equipment cannot be guaranteed.

REFURBISHMENT

Plant and equipment condition assessment

To perform a high quality refurbishment, the condition of the complete plant and its most important elements should be assessed at the beginning.
Assessment of hydro plant includes:

- Operating conditions
- Availability of water for addition of new unit(s)
- Needs and possibilities for increased capacity
- Review operating records Plant/unit flows, head and energy production.
- Review maintenance records
- Past and present maintenance programs
- Repairs—what and when
- Equipment design data Age and Materials
- Drawings and documentation
- Inspection of equipment
- General Condition
- Obvious Problem Areas
- Equipment tests and Test Data
- Personnel Safety
- Environmental Impacts

One simple method of assessment relating to age of different equipment in power plants is shown below in table of rapid Assessment Rating.

Plant Subsystems	Economical Lifetime (years)	Technical Lifetime (years)	Rapid Assessment Rating Good (<=)	Fair (<=)	Poor (>)
Electrical Installations					
Generators, transformers	25-40	30-60	25	45	45
High voltage switchgear, auxiliary electrical equipment, control equipment	20-25	30-40	20	35	35
Batteries, DC equipment	10-20	20-30	10	25	25
Mechanical Installations					
Turbines					
Kaplan and Francis turbines	30-40	30-60	30	45	45
Pelton turbine	40-50	40-70	40	55	55
Pump turbine and Storage pumps	25-33	25-50	25	33	33
Gates, butterfly valves, special valves, cranes, auxiliary mechanical	25-40	25-50	25	37	37
Civil Works					
Dams, canals, tunnels, caverns, reservoirs, surge chambers	60-80	80-150	60	100	100
Powerhouse structures, water catchment, spillway, sand traps, penstocks, steel linings, roads, bridges	40-50	50-80	40	65	65

Figure 2 Rapid Assessment Ratings [2]

The main causes of problems at the hydro power plant should be found out as well types of standstills, their frequency and duration. Load of the equipment, flows, temperatures and cooling systems should be checked up since all of them influence the operational life time of the equipment.
Changes that have happened since the moment of construction of the plant should be taken into consideration for planning of the scope of refurbishment, selection of new equipment, decisions on the increase of the output power or possible extension with a new unit.

Feasibility study

It is necessary to prepare several possible scenarios of refurbishment, check their feasibility and analyze the potential benefits compared to the funds invested and thus to choose the best variant.
The analysis should take into account: the expected benefits of increased power and increased production, reduced labor requirements, efficient use of water, improved equipment performance and increased availability, reduced cost of operation management and maintenance.
Feasibility study analyzes the costs associated with refurbishment. Part of the cost is required for determining the condition of the equipment in order to decide on the revitalization. Direct costs include revitalization of the cost of purchasing new and modification of existing equipment, the cost of planning, engineering, procurement study, factory testing, training, commissioning, cost control and inspection. In addition to the direct costs there are indirect costs of the necessary infrastructure for the project as well as investment capital costs.

Possible approaches to refurbishment

There are two main possible approaches to refurbishment having the following aim:

a) Extension of the hydro power plant life time;
b) Extension of the hydro power plant life time together with an increase of the output power or upgrade.

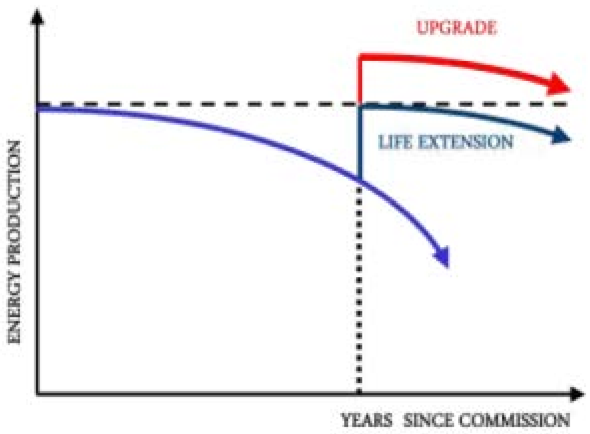

Figure 3 The figure illustrates how energy production is lost over time.
The Upgrade vs Life extension [2]

In the first case the existing equipment is replaced with new, more recent equipment while the plant output power remains the same. In the second case the existing equipment is being replaced with the new equipment with a higher output power. A detailed technical feasibility study is to be made for both cases as well as an economic profitability analysis of investment of additional assets into the increase of the output power regarding additional revenue

generated by the increased generation during the extended life time of the refurbished hydro power plant.
Life extension would therefore typically include:

- Generator and turbine dismantling
- Generator stator rewind
- Generator mechanical rehabilitation (generator, excitation)
- Turbine rehabilitation (runner, seals, wicket gates, speed governor)
- Unit auxiliaries rehabilitation
- Turbine and generator reinstallation and testing

There is also the issue of the stator core and the generator poles; however these are uncertainties and can be lumped in with the stator rewind.
Upgrade would typically include all of the modifications for the life extension listed above, plus:

- New turbine runner
- New generator in case of large output upgrade
- Allowance for additional turbine work (draft tube, intake)

Scope of refurbishment

A decision on a partial refurbishment of individual parts of the hydro power plant or on complete replacement is made on the basis of the condition of the equipment.
One of the important factors lobbying for the complete replacement of the equipment is its age. Some of the electric equipment features such as insulation are weakening during the time and it is hard to determine their changes by inspections and non-destructive testing. Therefore the safest thing to do is replacement of such equipment after a certain number of years.

System approach to revitalization of major equipment

A systems approach is needed to fully evaluate most rehabilitation. Changes in external system parameters or criteria, or the rehabilitation of one major piece of equipment can have a significant impact on other systems in the plant.
To illustrate this point, consider a case where a turbine runner is uprated to produce greater power output with improved efficiency. Such improvements are not uncommon but the impact on other parts of the plant should be considered, such as:

- Increasing water flow through the turbine can have an impact on the penstock in that larger flows will produce higher pressure transients due to load acceptance and rejection.
- Changes in governor stroke and timing and changes in pressure regulator valves (if applicable) are often required.
- The increase in turbine power requires a design assessment of such items as the shaft coupling, turbine shaft, rotor structure, and generator structure to safely transmit or handle the increased torque.
- An increase in turbine output requires a design assessment of the generator stator windings, stator core, and field to determine their ability to generate the increased power and the possible need to uprate the generator as well.
- The excitation system’s ability is to provide the required field current and the necessary voltage control, and to meet reactive power requirements should also be determined.
- The capability of the generator leads and circuit breaker (if applicable) to carry the increased current should be evaluated.
- The main unit transformer and associated transmission lines should be evaluated to determine that they can carry the increased power.

- The rating of the current transformers and associated metering and protective equipment should be evaluated based on the upgraded capacity of the generator. Generator protection settings should be reassessed.
- The generator cooling system and components should be evaluated for adequacy etc.

Revitalization of the water ways and turbine equipment

Revitalization turbines and water ways (channels, tunnels, pipelines) except returning to their original characteristics, usually has a significant potential to increase the output power generator. Modern hydraulic design and new technology of turbine equipment, as well as the reduction of losses in water ways allows to increase the power output of the turbine an average of 12% without additional increase in discharge and up to 30% while increasing discharge [2]. The increased turbine power is a base for further design of higher power generators and other electrical equipment.
An additional benefit of new hydraulic designs is that they are more adapted to pressure fluctuations, resulting in an increased operational range. This applies especially to Francis turbines with older design.

Refurbishment of generators

Key parts when a refurbishment of a generator is in question are stator winding, rotor winding, stator core, exciter and losses. An analysis of the condition of all the generator parts should be made to assess the generator refurbishment scope. In addition to the condition of the stator and the rotor whose failures cause the longest standstills, a care should be taken on the condition of auxiliary systems that tear and wear during the normal operation such as slip rings, brake shoes, oil-water and water-air coolers that can also cause significant outages. A special attention should be paid to the replacement of parts that are possibly made of asbestos or similar materials whose usage is forbidden nowadays.
When the condition of a generator is being assessed, in addition to the electrical features, mechanical features of the machines should be estimated as well.
The generator stator winding is considered to be a key indicator of the condition of the generator. The majority of studies and expert literature are dedicated to the understanding of factors influencing the operating life time of the stator winding. Figure 5 shows that the largest number of failures of hydro generators is bound to the fails of insulation.

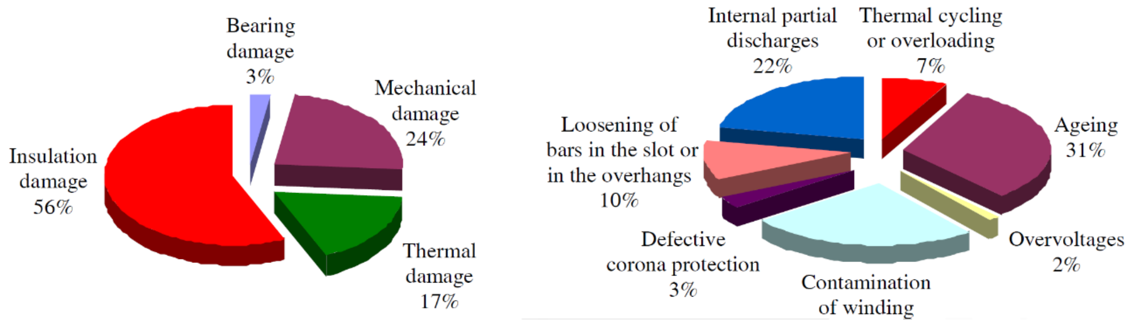

Figure 4 Damages of hydro generators (left) and root causes of insulation damages (right) [4]

Numerous longstanding generator standstills are caused by problems with bearings. Therefore the condition of existing bearings should be considered seriously as well. Existing bearings should be refurbished or reconstructed decreasing the possibility of their failure in the future. Oil and grease lubrication systems are bound to bearings. After a long time operation they can start leaking resulting in insufficient lubrication that can cause serious damages and environmental pollution. Therefore stated systems shall be necessarily refurbished and upgraded whenever it is possible.

Refurbishment is also a chance to replace existing DC or AC rotating machine exciters with technologically improved static excitation systems.

When the diagnostic tests are completed and certain calculations made, the complete condition of the existing generator can be estimated on the basis of collected data and a conclusion on the necessary scope of refurbishment and replacement of parts of the generator can be reached from the technical point of view. Economic circumstances of the referred project should be also taken into consideration to make a final decision on the stated scope of the refurbishment. It is clear that a complete replacement of the whole generator is the best solution, but it is also the most expensive solution as well and in some cases it has no economic justification. Other solutions understand a partial replacement of generator parts that depends on the above described analyses, economic circumstances, aimed operating life time of the refurbished generator, decrease of some risks, etc.

When a partial refurbishment of the generator is performed, a larger part of machine active parts or all machine active parts are almost always replaced:

- Stator winding – almost always
- Stator core – very often
- Re-insulation of pole winding – almost always
- Replacement of pole winding – sometimes
- Complete replacement of poles – often

A complete stator can be replaced additionally (and relatively often) or a complete rotor (rarely). The scope of refurbishment frequently comprises refurbishment of bearings, braking system, ventilation system, cooling system, etc. as well.

In addition to stated causes of refurbishment, effects of the refurbishment in the form of a possible increase of the generator power or in other words an increase of the generation of the electric power should be taken into consideration as well. More significant increase is possible if other parts of the hydro power plant allow that in the first line. The most important element here is the turbine that gives the necessary increase of power as well as the system that transmits the power into the gird (busbars, transformers, switches). Power increase is achieved through application of new windings having the insulation significantly thinner compared to the thickness of older insulations and therefore they can work at higher temperatures. Possibilities of the increase of the generator output power are described below in connection with replacement of some older insulation technologies with the most recent insulation technologies:

- From 1930 to 1955 lacquer and asphalt glued mica was used as insulation. When windings with modern insulation are used on generators manufactured before 1955, it is possible to increase the generator output power by 15 % if the same dimensions are kept;
- From 1955 to 1970 synthetic resins were gradually introduced for insulation with the improvement of the insulation from the class B to the class F. The output power can be increased from 7.5 to 10 % for generators manufactured between 1955 and 1970, since the thin "hard" F class insulation was not applied then;
- Since 1970 advanced polyester resins or epoxy resins have been applied to almost all the stator windings having the class F of "hard" insulation systems. For generators manufactured after 1970 minimum increases of power are possible decreasing the thickness of insulation and improvement of other insulation characteristics such as voltage gradients, thermal transfer, etc. [2].

In addition to the above stated increase of the generator output power, the power can be also increased on the basis of an improvement of the generator efficiency. Possibilities of the efficiency improvement depend directly on the decision regarding the scope of refurbishment, installed materials and optimization of the complete machine. We can say that the efficiency improvement is frequently connected directly to assets invested into the refurbishment. A more significant improvement of refurbished generator efficiency can be achieved by a decrease of losses in the iron and losses of the ventilation. New materials enable lower iron losses in the stator core compared to older generations of materials. When ventilation losses are being decreased the main challenge is decreasing of the cooling air flow without increasing of the temperature of machine active parts (stator and rotor windings). Such an approach can be generally applied to generators of middle / high speed (> 250 rotations per minute) designed with the old ventilation system concept. Potential of decrease of those losses when improving efficiency amounts up to 0.3 %. The typical total increase of the refurbished generator is from 0.2 % to over 1 %. In such a way the increase of the efficiency on projects in Scandinavia were the following: Imatra 7 HPP (Finland) over 1.5 %; Batfors HPP (Sweden) almost 1 % (0.98 %) [5].

Refurbishment of the excitation system

Expected aims of replacement of the excitation systems are in the first line: replacement of obsolete equipment with new equipment that is at the level of state of the art technological and technical solutions, decrease of costs and simplification of maintenance, achievement of better generator behaviour characteristics, increasing of the flexibility of the plant and assurance of a higher operational reliability and availability.
Due to the obsoleteness of the solution, direct current or alternate current excitation systems are most frequently replaced with static excitation systems.

Figure 5 New Končar excitation system of the synchronous generator at Varaždin HPP, Croatia

Requirements for the operation of the unit regarding the excitation system are frequently different from requirements before the refurbishment. First of all it refers to the following facts: units do not operate as basic, but as peak ones and it understands more frequent starts and stops, a wider range of reactive power regulation, requirement for a higher stability of the unit, as well as a higher influence to the stability of the electric energy system itself. All the listed requirements should be taken into consideration when a new excitation system is being designed. Possible new parameters of the synchronous machine should be also taken into consideration, especially when the output power of the generator is increased. The selection of the main technical characteristics of the new excitation system (nominal current, nominal voltage, maximum continuous excitation current, forcing factor, etc.) shall be coordinated with the data of the existing or a new synchronous machine.

CONCLUSION

Since a long time period has elapsed from the beginning of construction of the first hydro power plants and that the installed equipment has its operating life time, the equipment of a large number of plants has been and will be necessary to replace in the future with new equipment due to its obsoleteness and worn out condition. Refurbishment of any hydro power plant should result in a prolonged operating life time of the plant, improved safety and security of operation of the equipment, improved environmental protection and human health protection, advanced performance of the equipment adjusted to new operating regimes (increased power, increased efficiency, larger generation of the electric energy), improved reliability, increased availability, bettered monitoring of the operation of the machine and condition of the equipment, decrease of operating cost and decrease of maintenance costs.

The scope of refurbishment of generators varies from a case to a case and depends on the aims wished to be achieved by the refurbishment. In most of the cases, refurbishment results in the increased generator power and almost always in the increased efficiency of the generator.

Obsoleteness of the technology, expensive maintenance due to unavailability of spare parts and worn out condition of components resulting in a lower reliability of systems represent main reasons for the need of replacement and refurbishment of the excitation system. New state of the art micro processing excitation systems improve monitoring of the condition of processes, control and diagnostics. All the stated results in decreased operating costs and simpler excitation system maintenance.

Safer usage, control and protection of hydro power plants are achieved by the application of a state of art control , protection and measuring systems including monitoring system which enabling permanent monitoring of a range of operating parameters of the machine as well as monitoring of trends and changes of stated parameters.

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