Hydropower Refurbishment – Alstom's Methodology and Case Studies

Jean-Pierre Sungauer,
Head of Engineering,
Alstom Products India Ltd,
Vadodara, India

Alexandre Ferretti,
Manager, Technical Tendering,
Alstom Projects India Ltd
Vadodara, India

Fabio Sa,
Technical Specialist Generator Design,
Alstom Hydro,
Taubate, Brazil

Glenn Ardley,
Manager Generator Engineering,
Alstom Projects India Ltd,
Vadodara, India

Introduction

Alstom Power Hydro and its forefathers, such as Neyrpic, the Brown Boveri Company and ASEA, have been producing equipment for hydropower plants for over 100 years. Alstom has hydro-equipment engineering offices and workshops in North & South America, Europe and Asia. In Asia, Alstom has hydro turbine and generator manufacturing plants in Tianjin, China and Vadodara, India.

As hydropower plants age and new technology and materials become available, turbine and generator refurbishment can be justified economically on the basis of increased output, reliability and availability and reduction of maintenance costs. This paper will describe the need for power-plant refurbishment and give an overview of Alstom Power's methodology for addressing this need. This methodology will be demonstrated by several case studies, addressing turbine and generator refurbishment.

The Need for Power Plant Refurbishment

Repair, Modernize and Uprate

Repair is the most compelling of the reasons for refurbishment. In many cases, a component failure or deterioration will cause the generating unit to be unusable for commercial operation. Examples of this could be a stator bar failure to ground with associated core damage, a wiped bearing shoe or deep erosion in turbine components due to water characteristics. In other cases, the deterioration does not result in removing the unit from service, but rather de-rating of the output or a loss of efficiency. Examples of this could be leaking gates or seals or a stator winding that is close to the end of its design life. In some instances, the equipment requires frequent maintenance outages, resulting in a substantial reduction in unit availability. Modernization of equipment normally occurs because of advances in technology or the introduction of new materials and calculation techniques. Often, modernization cannot be justified commercially on its own merits, because of the need to take a generating unit out of service and often, to disassemble the unit for the refurbishment. However, modernization can be implemented when done in parallel with other refurbishment work. Examples of this would be re-insulating the generator field winding to Class F during the outage for a stator rewind, replacing grease-lubricated guide-vane bearings by self-lubricated bushings during a runner replacement or install a new instrumentation.

Generating-unit uprate is usually the most commercially profitable reason for refurbishing the plant equipment, because of the increase in generation or a higher capability to meet peaking demands. Depending on where the output limits exist, whether it be field-winding temperature or runner design, refurbishment can be implemented that can increase output by fifteen to forty percent, without having to modify civil works.

Attributes of a Good Technical Specification

A well-written, technical specification is the first step to a successful refurbishment project. It is the primary way that the plant owner communicates how the units will perform. Many times, we have seen refurbishment specifications that have not been clear; that have resulted in the owner not getting what he really wants or that have resulted in post-award, design changes (expensive). Sometimes, a specification will specify the design solution rather than the expected performance criteria. Occasionally, specified requirements will be mutually exclusive. A well-written specification can help ensure that the plant owner's needs and expectations will be realized by the project. In a specification, it is important to consider the following:

- When available, use international standards or industry-standard practices. When standards are not available, be sure that the specified requirement is based on experience.
- Specify the required performance or quantify an incentive/penalty rather than requiring a specific engineering solution. For example, do not specify grain-oriented steel for the stator core, rather set an appropriate penalty for high losses.
- Calculation tools today are more powerful than previously, and more of the design space can be investigated. Do not limit the design space unnecessarily or use the existing performance as a gauge for refurbished performance.
- Assembly and detailed, component drawings should be given in the specification.
- The refurbishment requirements have to be clearly stated in terms of required operational performance and commissioning and acceptance test results.
- The laws of physics cannot be changed by a specification.

Alstom's Methodology for Equipment Refurbishment

General Philosophy

The primary differences between the design of a new generating unit and refurbishment design are the interfaces that have to be considered in the refurbishment design. It is obvious that the new, refurbished components must match and mesh with the existing components that are not being replaced. Because of this, good solutions are more difficult for refurbishment design than that for new units. The other main difference is that the existing machine must be synthesized.

The available design space for refurbishment is established by the interfaces. The first step is to understand the refurbishment requirements and the interfaces. Usually, the specification will not contain all of the detailed information about the interfaces and a site visit is required. The purpose of the site visit is to gather information to characterize the existing generating unit and to establish very clearly, the interfaces. The specific activities during a site visit depend on the scope of the refurbishment, but in general the following are required:

- Historical, operational data and maintenance records,
- Performance test results from unit commissioning or previous refurbishment,
- Access to OEM drawings,
- Sufficient access to the unit for measurements and visual inspection.

Depending on the scope of the refurbishment, a site visit/inspection can take from a few hours to several days. A second visit, after award of contract, is absolutely necessary.

The design process has two major steps, pre-award or tendering and post-award or basic and detailed design. The time available for tendering is usually very short and does not allow for in depth engineering studies. This stage focuses on getting enough information to establish performance guarantees and a cost estimation for the project. Alstom has developed calculation tools that can do these analyses in the available time. After award of contract, basic design focuses on detailed studies of the components and their interfaces to the existing equipment. A more-exhaustive site inspection is done at this time. Whenever possible, Alstom standard solutions will be used to implement the project design, however, because of the nature of refurbishment, this will not always be possible.

Generator-Specific Methodology

Tendering

The process begins with a thorough review of the specification, available information and a site visit. The site visit is critical to understand the unique nature of the machine and the environment in which it operates. Vital to a successful design are accurate dimensional measurements and historical data of excitation requirements, operational temperatures and segregated losses. Critical dimensions taken from OEM drawings should be checked with a physical measurement, as they may not represent the as-built data. The site visit also provides and opportunity for plant owners and equipment vendors to discuss and clarify the refurbishment requirements.

Alstom's modeling tools for generator refurbishment are analytical and numerical calculations that have been incorporated into several software packages. The scope of the refurbishment determines which of the packages are applicable to the design studies, but the first step is always done with a generator calculation and optimization tool.

With the calculation tool, the existing generator is modeled. Input for calculation includes the generator's rating, operating conditions, geometric data, material characteristics and experience-based, correlation factors. Calculations of excitation requirements are compared to measured values, including the open and short-circuit characteristics, and the model is refined. Similarly, measured segregated losses and measured temperatures are used to further refine the model. This is an iterative process. Basic mechanical calculations are also performed. However, the calculation tools do not replace the experience and creativity of the design engineer.

When a good model of the existing machine has been achieved, manual and automatic algorithms optimize the refurbished components. The available design space is limited by the interface requirements, but the analysis can be tailored to optimize only in the available space. Electromagnetic, finite-element analysis is used to verify the excitation-requirement calculations. If the scope demands, other software packages are applied to do more-detailed mechanical, bearing and ventilation calculations. Refurbishment tendering designs always undergo a rigorous design review, because they can present significant technical risk.

Basic and Detailed Design

Basic design follows the award of the contract. The actual studies performed depend upon the scope of the refurbishment and the nature of the interface requirements. The most usual scope for generator refurbishment is replacement of the stator core and winding. This is often in conjunction with a generator uprate. In this case, we recommend that the field coil insulation be uprated to Class F. The interfaces in this case will be the stator frame, the ventilation system, and possible interference between the winding and the upper bracket and deck plates. A new stator-core keying and clamping system will be required. Whenever possible, Alstom common design standards are used to realize the design, but often special designs are required to accommodate the existing frame design. In the case of an uprate, a detailed ventilation study will be performed. If the existing generator has had problems with core buckling, sole plate modifications may be required to allow for proper radial movement. In this case, the frame may also require replacement.

Airgap stability problems may be another cause for refurbishment. This occurs when the stator and/or rotor stiffness are not sufficient to resist tangentially-unbalanced magnetic forces across the airgap. These forces are usually due to eccentricity between the stator and rotor or ellipticity in either component. The basic design studies will focus on the root causes, and then, on appropriate solutions. These may be re-shrinking of the rotor rim, shimming of the poles, redesign of the stator core and winding or complete replacement of the stator.

Whatever the refurbishment scope, technical experts from Alstom's generator-technology center in Switzerland, engineering, manufacturing and installation review the design solutions at critical stages of the process. Following the basic design studies, detailed engineering turns the solutions into manufacturing and installation drawings. The implementation step follows the same process as that for new generators.

Turbine Specific Methodology

Alstom has developed a methodology for refurbishment of turbines that is the result of experience from similar projects, R&D, utilization of accurate tools and model tests. This methodology can be applied to all objectives in the refurbishment, but in specific cases, different approaches can be used. The process is divided in three main steps, as follows:

Tendering Step

The main objective of this step is to understand clearly what is the target of the project. The most common objectives are classified as output increase, efficiency increase, improve the stability, solving problems with cavitation or abrasion and any combination of the above.

Based on the targets, it is important to collect enough information about the turbine to conduct studies to evaluate the possible modifications. Due to the short time during tendering, it is not possible to perform in-depth and advanced calculations. The challenge at this stage is to define, with some basic analysis and simple calculations, the performance of the generating-unit after refurbishment. The boundary conditions (dimensions and interfaces) and restrictions (overpressure and overspeed) also need to be checked in this moment. The analysis in the tendering step can be divided as follows:

Inlet (Spiral Case & Stay Vanes)

It is not common to modify the spiral case in a refurbishment project. The cost / benefit relation is not favorable and technically is impossible for vertical turbines, but it is necessary compare the spiral-case section with the modern spiral case designs. In specific turbines that use a semi-spiral case, small modifications can be done with an acceptable cost, but this practice is not common. The modification of the spiral case normally is restricted to adding guide vanes in the stay ring to improve the flow behavior.

The stay vane profile needs to be analyzed and compared with modern profiles. Another important aspect is the angle that the stay vanes impose on the flow. Modifications in the stay vanes are possible, and the effect normally is interesting. Mechanical aspects need to be verified in the stay vanes, such as a history of cracks and vibration.

Distributor

The replacement of the existing guide vanes by new, more-adapted profiles generally leads to a significant improvement in performance. In the tender stage the existing profile is compared to modern Alstom profiles, to verify the level of improvement that can be realized. The new guide vanes have the advantage in relation of the existing do the better surface quality and consequently lower losses.

On the mechanical side, it is important verify the operating mechanism, servomotor strokes and bushings. The modifications in these components are important to assure the correct opening for the new guide vanes, to support new efforts and to reduce the maintenance time.

Runner

The runner is the most important component in a refurbishment project. Generally, a new runner design is developed for the specific conditions of the turbine. During the tender stage, the analyses are restricted to dimensional aspects and the interface with the other components.

At this stage, the cavitation conditions are analyzed. Based on the new discharges, characteristics of the new runner, standards and customer requirements, the material of the new runner is defined. Old runners generally are made of carbon steel, and new runners of stainless steel, which has a better performance in cavitation conditions. For turbine stability, it is necessary to verify the conditions of aeration. Additional benefits can be obtained by the analysis of the labyrinth gaps and geometry.

Draft Tube

After the runner, the draft tube is the major component affecting the turbine behavior. The importance of the draft tube increases proportionally to the inverse to the head. At the tendering stage, the analysis of the cross-section and the water velocity is mandatory. In cases where the discharge increases substantially, it is important to take care operational instabilities. There are several situations where it is possible to modify the draft tube, but normally this has civil consequences. In this situation is important to be supported by a civil specialist.

Mechanical components

Mechanical components need to be verified considering the new characteristics of the unit. Guide and thrust bearings need to be analyzed considering the loads from the new machine, such as a different axial load, runway speed and overspeed. Generally parameters such as overpressure need to be maintained in the refurbished unit, even if there is an increase of discharge. For this situation a transient hydraulic calculation is mandatory to define new values for the closing and opening times of the distributor.

Others customer requirements like abrasion and fatigue of the core components need to be analyzed. For all these items there are several solutions that can be proposed. For abrasion, different material and/or coating can be used in the runner, guide vanes and part of the head cover and bottom ring. Fatigue problems can have hydraulic or mechanical reasons, and the solution can require an in-depth investigation that generally is done in the first design stage.

Most of these analyses are done with simple tools and calculation methods, and need to be confirmed with more sophisticated tools in the first stage of the design.

Design step

In the design step, all items analyzed in the tendering stage need to be deeply studied, and more information needs to be collected at site. If a performance test of the units is not available, the first action is conducting a prototype performance test following IEC standards. This test is essential to define the real performance of the equipment, and can be the base for the future comparison. At the same time operational conditions need to be investigated.

A detailed inspection in the equipment is also necessary and the real profiles of the wicket gate and stay vanes need to be confirmed. Alstom can execute this inspection using different methods such as templates or 3D-measurement arms. Other dimensions are verified such as the main diameters of distributor and labyrinth dimensions.

The analysis of the existing turbine is done when the site activities are complete. In this moment, the breakdown of losses of the stationary components is defined. The first step of this analysis is always one-dimensional for components like spiral case and draft tube. For stay vanes and guide vanes, a single cascade analysis constitutes the basis. These studies permit to determine the parts, which require a more exhaustive analysis [1].

The next step is to conduct a CFD calculation for the main components. The objective is to determine the flow behavior in the existing conditions with different discharges. From the results of the CFD calculation for the existing conditions and the analysis of the hydraulic experts, the aspects that can be improved are identified. CFD calculations for the modifications proposed be done to compare with the existing conditions. These calculations and analyses are crucial to reach the targets in the refurbishment project. Every site is unique in its design and operation, and every project is different in its technical requirements. It is necessary to carefully adapt the new design to the existing components and to the required performance [2].

Examples of the CFD analysis for static components can be observed in the Figures 1 and 2. Figure 1 shows the velocity fields for the stay guide vanes in the existing condition and with the new profile. A smoother flow transition is obtained due to the better stay-vane profile.

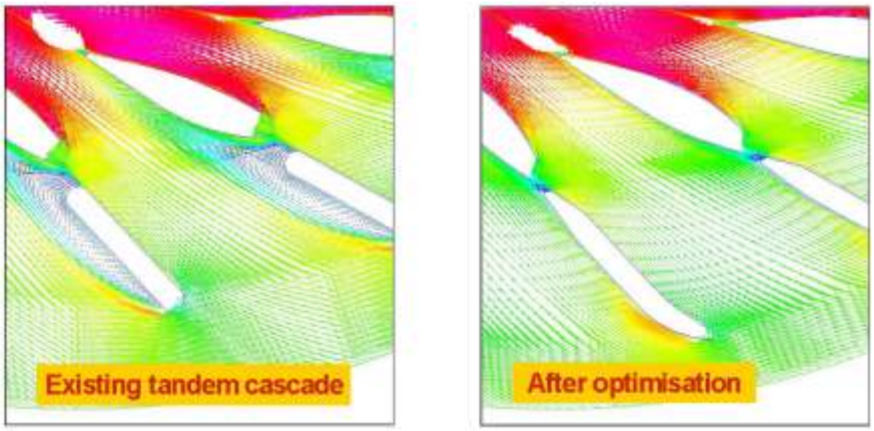


Figure 1. Velocity field an stay vane and guide vane [2]

For distributor, CFD calculations are done to verify the flow behavior and the losses in guide vanes. Significant improvement has been achieved in the most recent Alstom refurbishment projects. Non-symmetrical profiles and guide-vane lengths to reduce the overhang have shown favorable effects for performance and cavitation.

Figure 2 presents the comparison between draft-tube streamlines. It is possible to see the different behavior between each condition. In this case the modification in the draft tube was restricted to decreasing the elbow outlet height by covering the lower part of the draft tube.

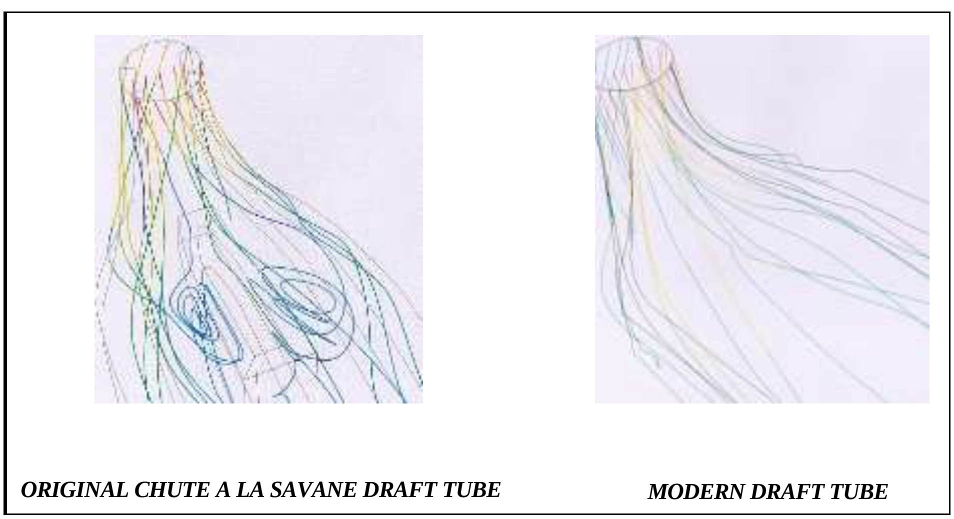


Figure 2. Original and modified draft tube behavior [2]

After finishing the analysis of the spiral case, distributor and draft tube and determining the other modifications that will be done to the existing condition, a new runner needs to be developed. For the runner development, there are several boundary conditions imposed by the existing dimensions and hydraulic conditions. In this stage, sophisticated methodologies are used to have the best possible design for the refurbishment conditions. In recent projects, Alstom has used a genetic optimizing tool and CFD viscous calculation to define the profiles and analyze the flow. Hydraulic experts can select the parameters and the degrees of freedom that tool will modify. The optimizer then selects the values for the geometrical parameters. The results of this process have produced high-performance runners for refurbishment designs. Figure 3 shows one example where the optimizer tool presented a surprising inlet profile for Shasta Powerplant refurbishment.

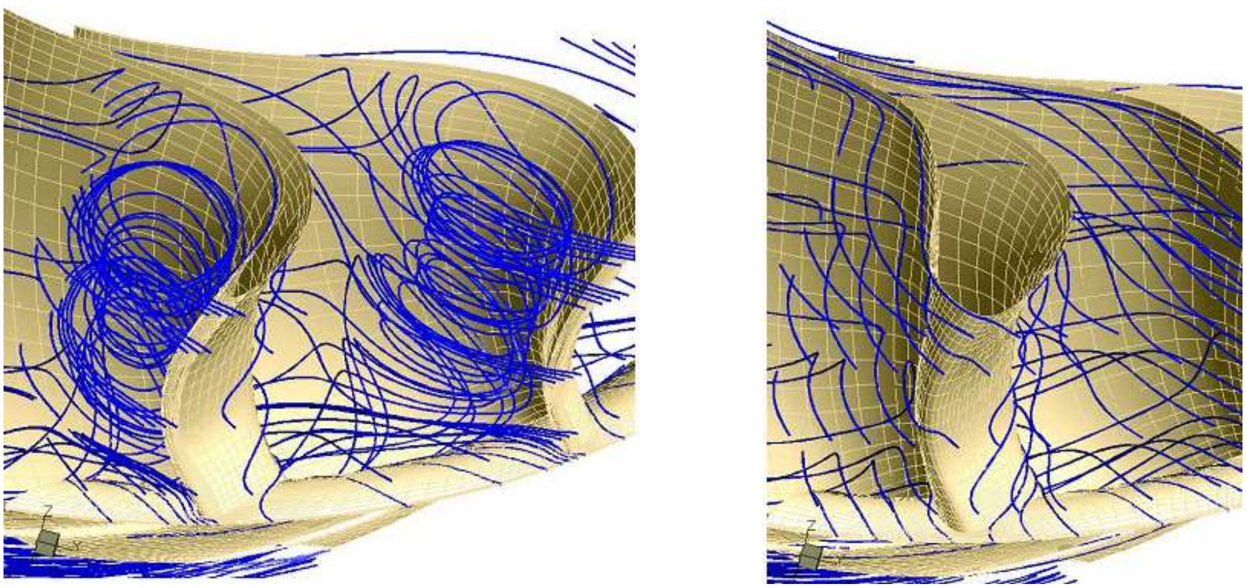


Figure 3 – Comparison between first profile and final profile defined by the optimizer

After completing all simulation steps with CFD, the final step is to perform a model test to compare the existing and new conditions. The model test is necessary to confirm the design before the actual modifications are done. The model test also checks cavitation performance of the new design and pressure fluctuations. Also, it is useful because it is possible to compare both designs in controlled conditions. In refurbishment projects of small power plants, the cost of a model test is prohibitive, but for large turbines this resource is very useful to reduce the risks.

The other aspects analyzed in the tendering stage such as aeration, labyrinth gap, runaway speed and thrust load are confirmed in this step. Based on the results of model test and simulations, the modifications of the other components are detailed.

Implementation step

The manufacturing of the new components and the modifications of the existing parts are key success factors in every kind of projects, especially for refurbishment projects. The modifications of the existing parts need to be executed with extremely competence, because the final performance of the prototype depends on this work. Modifications that involve civil works are also a challenge in existing power plants.

The manufacturing of the new components normally follow Alstom's standard processes to assure the best product quality. Adjustments in the site during erection are a normal practice in refurbishment project, because the normal pre-assembly conditions for new turbines are not applicable in these cases.

After commissioning, the site acceptance test is performed according IEC standards to compare the performance between the old and refurbished turbines under the same conditions. This is the definitive way to prove that the project reached the targets.

Execution Aspects

In refurbishment projects, the objective of the customer is maximize the return on investment. Several aspects like performance, cost of the project and the final generation affect the result. One important aspect that affects substantially the return of investment is the total schedule and the outage time of the units.

The capacity of one company to complete the project in the shortest possible time, with the minimum of outage time, generally is an important decision factor for the customer. A few months of no generation can represent a substantial reduction of the return in the project. To avoid delays and unwelcome surprises during project execution, every action needs to be exhaustively planned, and the team in charge of implementation needs to have a substantial experience with similar projects.

Generator Case Studies

Rocky Reach, Units 1 to 7

Customer: Chelan County PUD, Wenatchee, Washington, U.S.A.

OEM: Westinghouse

Rating: 120 MVA, 15 kV, 90 rpm, 0.95 pf

Reasons for Refurbishment:

- Airgap instability – rotor / stator rub on one of the units.
- Some stator-core buckling and stator shape becoming square (stator core originally built in four sections)
- Increase of generator efficiency.
- Some units very noisy, >95 dB outside housing.
- Life extension / increased availability / reduced maintenance costs & outages.

Refurbishment Scope:

- Stator frame, core & winding (new stator, except for embedded part of sole plates)
- Rotor hub, spider, rim & poles (new rotor, except for shafts)
- Almost a complete new unit except for shafts, brackets and bearings.

Uprate: No uprate of nameplate output.

Special Design Requirements:

- High efficiency – High evaluation for low losses, very high penalty for missed guarantee.
- Airgap shape requirements – Tolerances half of usual IEC/CEA standards.
- Very low audible noise requirement.
- High evaluation for short installation outage.

Interface Requirements / Design-space Restrictions:

- Upper-bracket supports on top of stator frame.
- Size of housing and clearances to upper deck plates set the frame OD and axial length.

Design Solution:

Because of the large scope, including a complete rotor and stator, the interface requirements are not very restrictive. Actually, in this case, the housing size allowed an increase in both the frame and core radial depth. The efficiency evaluation was approximately ten times the usual value, making the cost of material almost negligible by comparison. Therefore, to address the high efficiency requirement we added active material and reduced the airgap length until we reached the SCR limit. The efficiency was increased by more than 0.5% with respect to the existing generator to almost 99.0%.

To address the airgap stability issue, the rim was heat-shrunk for full overspeed. The rotor spider and stator-frame feet were designed with Alstom's patented oblique elements to allow tangentially-uniform centrifugal and thermal expansion. The oblique-element stator feet were redundant as, with the very low losses, the stator temperature rises were also very low. The stator-core resonant frequencies were carefully checked to ensure a large distance away from all of the forcing frequencies.

To reduce the outage time to a minimum, the rotor and stator are built in the erection bay of the power plant. When both are complete, only then is the existing unit taken out of service. For the last unit completed, the fourth of seven, the time between commercial service of the existing unit and the new unit was only 45 days.

Generator acceptance tests confirm conformance with all technical requirements. Online monitoring has demonstrated an out-of-tolerance airgap shape. The out of tolerance condition exists for only part of the year, with the annual, cyclic variation directly proportional to water temperature. The cause was identified to be concrete expansion and contraction. A solution is currently being implemented.

Crystal Power Plant, Unit 1

Customer: United States Bureau of Reclamation, Montrose, Colorado

OEM: General Electric

Rating: 35 MVA, 11.0 kV, 257 rpm, 0.9 pf

Reasons for Refurbishment:

- To realize the uprate potential.

Refurbishment Scope:

- New stator frame, core & winding

Uprate: 25% uprate from original 28 MVA, 1.0 pf. (12.5% increase in MW)

Special Design Requirements:

- The existing nameplate rating was unachievable due to rotor-temperature limit.
- Reuse the existing rotor, if possible.

Interface Requirements / Design-space Restrictions:

- Existing axial length, housing diameter and rotor diameter.
- Existing sole plates.
- Deck plate supports on top of frame.

Design Solution:

The challenge with this refurbishment design was to realize the 25% increase in MVA with the existing rotor. As well, the power factor changed from 1.0 to 0.9 overexcited to satisfy new, power-system requirements. The existing field-coil insulation was NEMA Class B, and the actual capability was a little less than nameplate, with a rated field temperature rise of 60 kelvins. It was obvious that no single modification would satisfy this requirement.

The first thing to do was to upgrade the field-winding insulation to Class F, which would allow a temperature rise of 80 K. Note that it is usual in the U.S. for customers to require Class F insulation but not to exceed Class B temperature rises. The next modification was to increase the series turns by approximately 20%. This will also decrease the radial cross section of the core, but the net effect was to reduce the excitation requirements. The third modification increased the yoke (back of core) depth, reducing the yoke flux density and the corresponding magnetizing force. The final modification was to shorten the airgap length just enough to bring the excitation requirements and field temperature rise into line with the new nameplate rating. During performance testing in the autumn of 2004, the field-temperature at the new rated load and power factor was measured to be 78 K.

Turbine Case Study

Saint Lawrence, 8 BLH units

Customer: New York Power Authority (NYPA)

OEM: Baldwin, Lima & Hamilton

Rating: 8 Propeller Turbine, 85 kHp (62.5 MW), 81 feet (24.7 m) nominal head, 94.74 rpm

Refurbishment Scope:

- Turbine runner

Uprate:

Special Design Requirements:

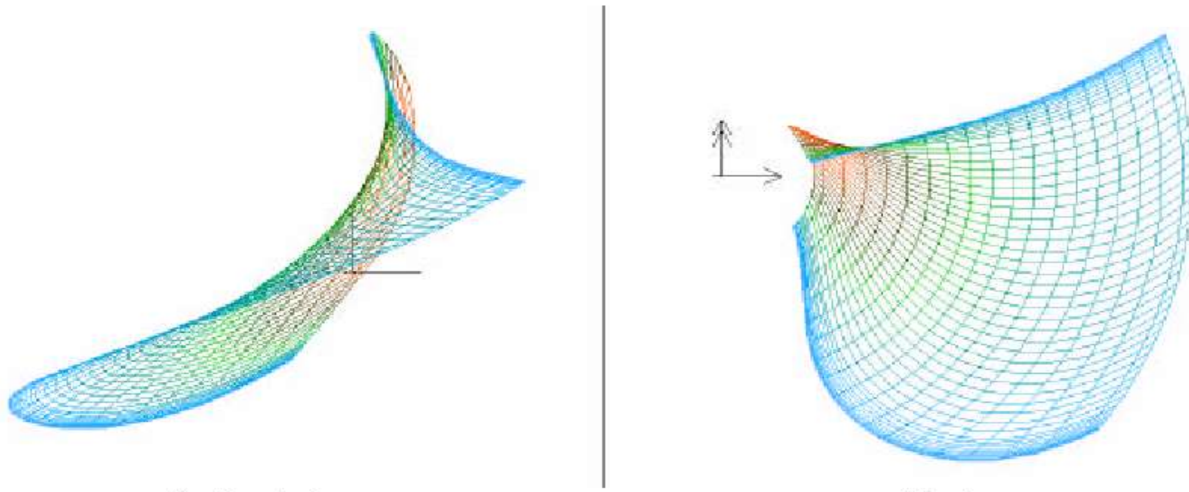
- Increase overall efficiency
- Translation of the peak efficiency to higher load
- Reduction of erosion by cavitation
- Increase of the stability of the turbine

Hydraulic Problems:

The goal of the refurbishment has focussed on overall efficiency enhancement, translation of the peak efficiency to higher load and reduction of cavitation erosion. The customer required high efficiency levels from the new runner as well as better cavitation behavior. The original units suffered from cavitation wear and were often repaired by welding. It is desired that the new runners have reduced cavitation to avoid frequent repairs. The exiting units show pressure fluctuation that affected the stability of the turbines.

Design Solution:

The methodology was applied and the main modifications in this refurbishment were the runner. To achieve the targets defined by the customer in relation to cavitation, output and efficiency a complete CFD calculation was performed for all components of the turbine. For cavitation, different numerical investigations were done for the analysis of existing hydraulic components. With good accuracy, the results predicted the flow angles, and consequently, a blade design able to perform well in the operational range defined by the customer. Based on these results, a new runner was developed. The blades have a twisted shape, as presented in Figure 4. Cavitation behavior is presented in Figure 5.



Sectional view. Up view.

Figure 4. Modern profile of a propeller blade

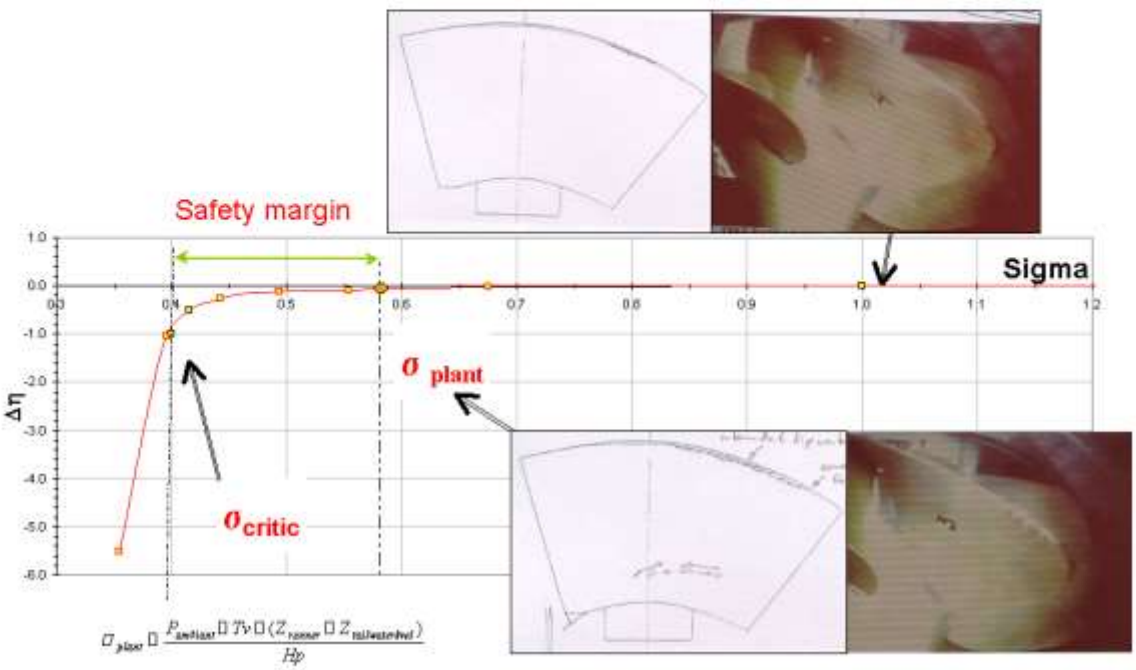


Figure 5. Sigma break curve at full load up to maximal flow near the nominal net head

The model tests in the Alstom and EPFL laboratories confirm the CFD simulation. During the manufacturing the runner profile was done by a 5-axis machine, to assure that the geometry calculated is accurately reproduced. The final runner is showed in the Figure 6.

Figure 6. Finished runner

The prototype test confirmed the model test results and it was possible to show the efficiency and output targets were reached. Figure 7 presents the comparison.

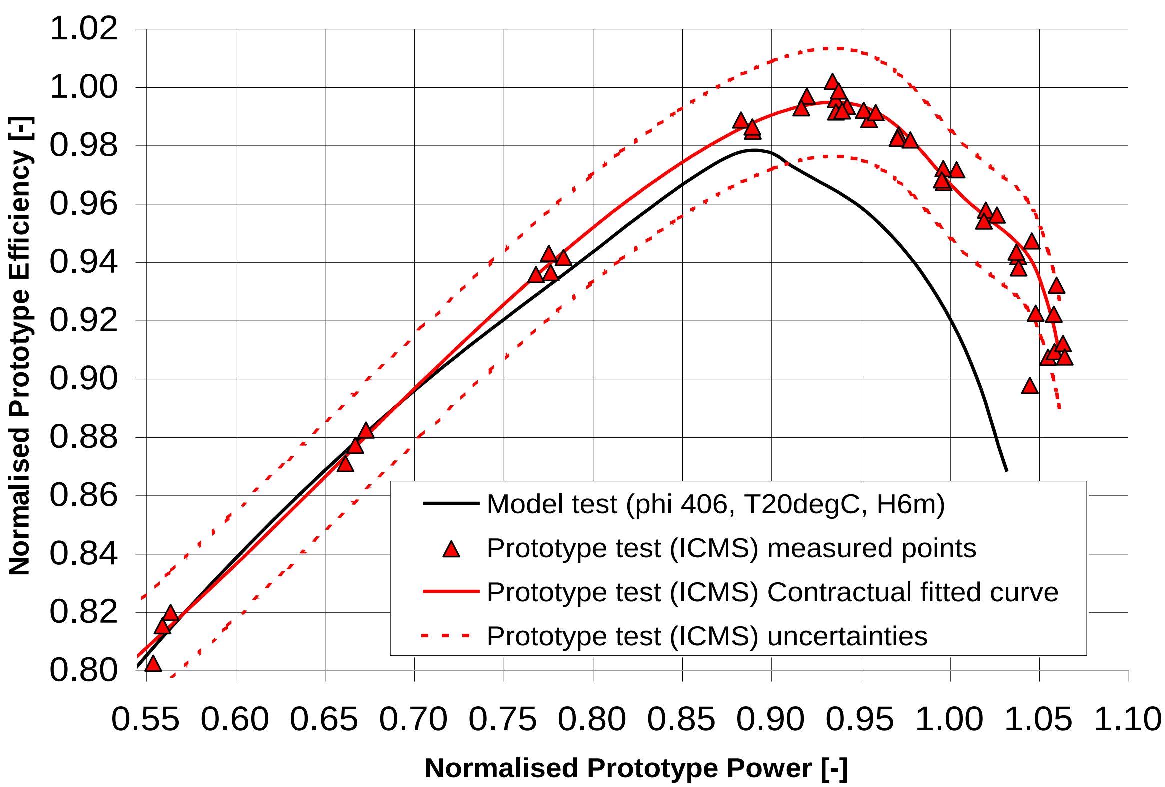


Figure 7. Comparison of model and prototype efficiency

Conclusion

Refurbishment of power-plant equipment is usually driven by the need for improved reliability, availability or an uprate of output or increase in efficiency. Generally, refurbishment design is more challenging than the design of new generating units because of the need to interface with existing components.

From the equipment supplier's perspective, there are three main stages of a refurbishment project. The tendering stage, which is usually short in duration, is characterized by collection of data and a relatively quick analysis of the existing situation and technical solutions. Good tools and experienced designers are vital to the success of this stage. Basic design is the second stage. This is where in-depth analysis and calculations are performed. Very specific solutions are developed at this stage and the performance is calculated more accurately than that from the previous stage. The implementations stage is characterized by detailed design, production of drawings and installation of the refurbished equipment.

The integration between generator and turbine is essential in all kind of projects, but in refurbishment cases, it is much more important because the boundary conditions are much more restrictive.

The Alstom methodology presented has been efficient for projects in every corner of the world. The cases presented show typical examples of the difficulties and the solutions that Alstom Power develops for refurbishment projects.

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