The Challenge of Refurbishing Hydroelectric Generating Stations

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Executive Summary

Although new hydroelectric generating stations are still being built all around the world, and a number of projects for future generating stations are being studied, the vast majority of stations now in operation were built over 20 years ago, and some even date back more than 50 years. There are numerous factors that make refurbishing these generating stations inevitable, the most obvious being equipment wear, fouling of pipes and greater maintenance requirements.

Not only are these refurbishments associated with repairing or replacing equipment and piping, they are also often linked to an increase in turbine-generator unit capacity. In fact, new technologies offer operators the option of increasing the power produced by turbine-generator units (additional capacity), most specifically by improving the turbine wheel blade or penstock wall profiles. For example, 50% additional capacity for a 50 MW unit translates into an increase in annual power output of 219 GWh, considering a 50% utilization factor. If we consider a production cost of 2.5 ¢/kWh and a sales price of 7 ¢/kWh, this results in a gross annual profit increase of $9.9 million. Even for a project costing only a few tens of millions of dollars, the return on investment is recovered within just a few years. In order to proceed with increasing a generating station's capacity, the mechanical and electrical auxiliary systems connected to the turbine-generator units often require refurbishment due to the increased requirements associated with the higher turbine-generator unit capacity, such as a greater need for cooling water and for air to the air brakes and to the regulation system.

Years ago, medium and large generating stations (with capacities varying from several hundred to several thousand megawatts) were on the receiving end of many refurbishment projects, since even a slight increase in capacity resulted in significant production increases. However, with the price of electricity rising continuously, it has also become profitable to refurbish smaller generating stations, those with capacities of a few tens of megawatts. This is true for both private generating stations and those run by larger government agencies.

This white paper relates to the mechanical aspects associated with refurbishing hydroelectric generating stations.

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Business Challenge

Why has it become critical to refurbish generating stations?

- **Because equipment and piping have aged.** The older equipment gets, the more maintenance it requires; piping becomes fouled to the point that fluid can no longer flow through it efficiently. In one generating station, pipes that originally had a 4-inch diameter had become fouled to where the actual diameter was less than 2 inches, not to mention the fact that it also meant the roughness of the interior wall had increased, which added even more load loss. Furthermore, modern versions of station equipment are much more efficient than their predecessors from 20 or more years ago.
- **For reliability and safety.** Some equipment and piping have reached the end of their service lives. The need to replace them is inevitable. Increased reliability decreases maintenance requirements, and by that very fact, reduces the risks associated with servicing them. A reliable system rarely breaks down and contributes to ensuring network reliability and therefore user safety.
- **For environmental considerations.** Old generating stations are not always equipped with systems to treat drainage system discharge and wastewater from sanitary facilities. In those instances, the discharge does not comply with environmental standards currently in force.
- **For economic considerations.** Firstly, renovated equipment will require less maintenance, thereby reducing operating costs. Furthermore, the productive capacity of existing equipment will be increased.

The challenges are economic, technical and social in nature. Examples of these challenges are presented

hereunder, and the solutions implemented to overcome these challenges are presented in the next section.

Examples of economic challenges

- **Keep the generating station at least partially, if not fully, operational, minimizing the need to shut down the turbine-generator unit or even the entire generating station.** For example, based on a sales price of 7 ¢/kWh, shutting down a 150 MW unit for one hour translates into a $6,750 loss.
- **Minimize installation costs.** Proposing pre-assembled equipment and piping on common bases helps reduce job site installation time. It also contributes to minimizing shutdown time.
- **Increase unit capacity by improving efficiency.** For example, replacing a turbine wheel with one that has better-profiled blades, or improving the draft tube profile helps to reduce hydraulic losses, which consequently increases efficiency and power produced by a turbine-generator unit.

Examples of technical challenges

- **Install new equipment in an area occupied by existing equipment.** 3D-imaging techniques are extremely helpful in this type of situation, since they provide a true-to-life representation of existing conditions, thereby minimizing the need for additional site visits. These techniques, used within the framework of preliminary engineering, help to establish better solutions and accurate estimates of required work and equipment. This ultimately facilitates the detailed engineering phase.
- **Re-use certain irreplaceable equipment or pipes.** For example, in one generating station, pipes embedded in concrete could not be replaced. It was necessary to find a way to clean them, so that they could be re-used.
- **Isolate certain sections of piping where the isolation valves intended for that purpose are no longer functional.**

Examples of social challenges

- **Keep the generating station operational to ensure water continues to flow.** For certain generating stations located near urban areas, the forebays and tailbays have shoreline residents, so drawdown for these bays is very limited. Since the levels in these bays depend on the rate at which water flows through the generating station, the range of values in which they must be maintained is very limited. At one generating station, the spillway gates were no longer operational. As a result, all of the water from the river had to pass through the units. In this specific case, the generating station could only be completely shut down for very short periods of time, in order to prevent flooding the forebay shoreline residents.

- **Control water discharge into waterways.** At another generating station, water that had collected in the bottom of the turbine shafts was drained directly to the draft tube diffusers of turbine-generator units, and therefore directly into the river. Since this water contained oil, albeit in small quantities, it did not meet current environmental requirements. At this same generating station, the drainage well that collected water from the entire station, except for the aforementioned wells, also collected oil and grease from time to time. A portion of this oil and grease was found in the water pumped from this well directly into the river. Once again, this water did not meet standards. There are still generating stations today that discharge wastewater from sanitary facilities directly into the waterways.
- **Find a solution when products used in the past no longer meet current standards, most specifically from an environmental standpoint.** Examples are the use of thermal insulating material containing asbestos on pipes, and the use of lead-based paints on equipment and pipes.
- **Preserve the heritage value of certain buildings.** For example, one generating station had restrictions regarding possible locations to install new fresh air intake louvres, ensuring the aesthetic appearance of the building would not be hindered.
- **Improve equipment use and maintenance.** This challenge is also one relating to safety. At yet another generating station, replacing and re-locating equipment and valves helped to improve equipment accessibility and valve manipulation. Since equipment was easier to access and it required less effort to manipulate the valves, worker safety was improved.

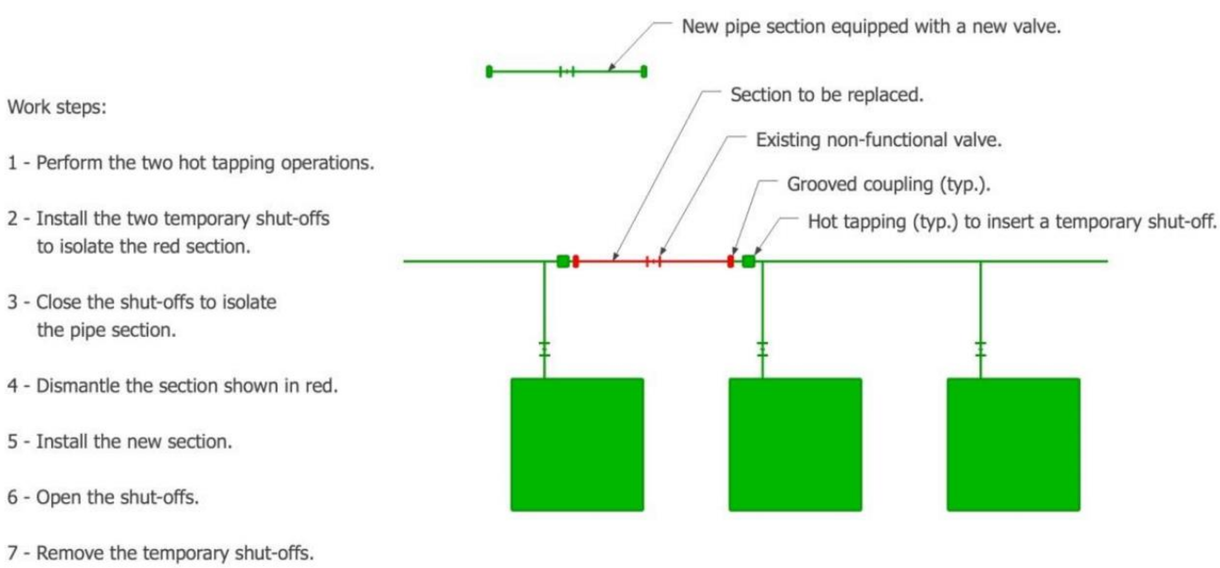
Description of the Solution

The following examples illustrate the solutions proposed for overcoming some of the challenges previously described.

Challenge: Keep the generating station operational.

1. Problem: Since they were so fouled, the valves that were used to shut water flow and isolate the cooling water supply and return collectors could not be turned off.

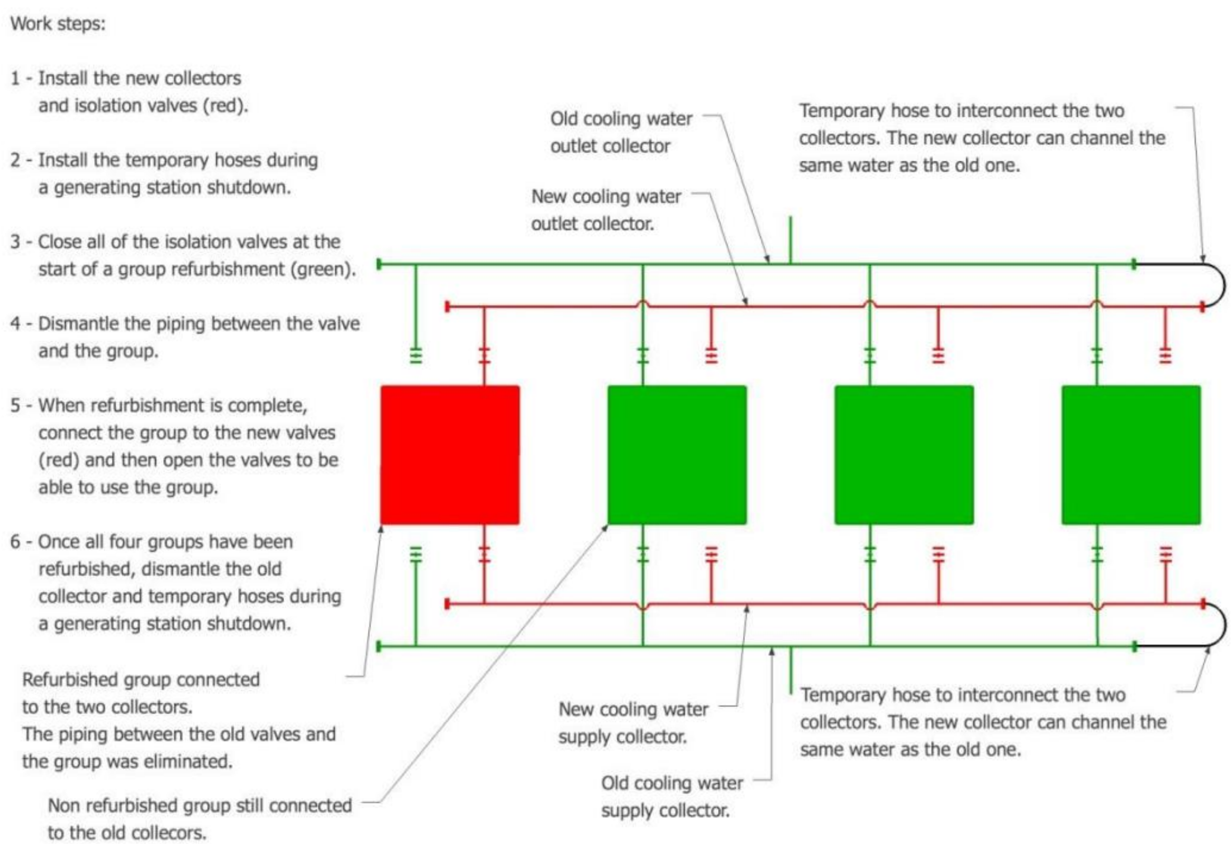
2. Solution: The hot tapping process was used to insert temporary shut-offs in the collectors; these shutoffs could then be used as shut-off valves to isolate the sections necessary. Since the piping had been assembled using grooved couplings, it was possible to install new sections of piping that were also similarly grooved, but that were also equipped with new isolation valves to replace the existing sections. The temporary shut-offs could subsequently be removed. The newly installed valves provided the necessary shut-off function. Refer to the diagram hereunder.



Challenge: Minimize generating station shutdowns.

1. Problem: Since the spillway was unusable, it was necessary to minimize the time the generating station was shut down so as to prevent flooding the station's forebay shoreline residents.

2. Solution: To add and remove hoses and temporary connections, only two generating station shutdowns lasting less than two hours were required. Refer to the diagram hereunder.



Challenge: Minimize turbine-generator unit shutdowns.

1. Problem: The operator requested that the unit shutdowns not hinder generation.

2. Solution: The work affecting equipment connected to a unit was planned to be performed during the unit's planned shutdown periods. It was therefore possible to drain the unit's penstock, thus dismantling and replacing equipment and pipes connected to the penstock.

Challenge: Re-use certain spaces.

1. Problem: Piping to connect equipment located on two different levels had to be installed. It was impossible to run the pipes without having to go through concrete ceilings and walls. However, these holes presented a great risk due to the number of pipes and conduits that were buried.

2. Solution:

   a) Dismantle a useless pump and the pipes connected to it. The pipes were 10 inches in diameter.

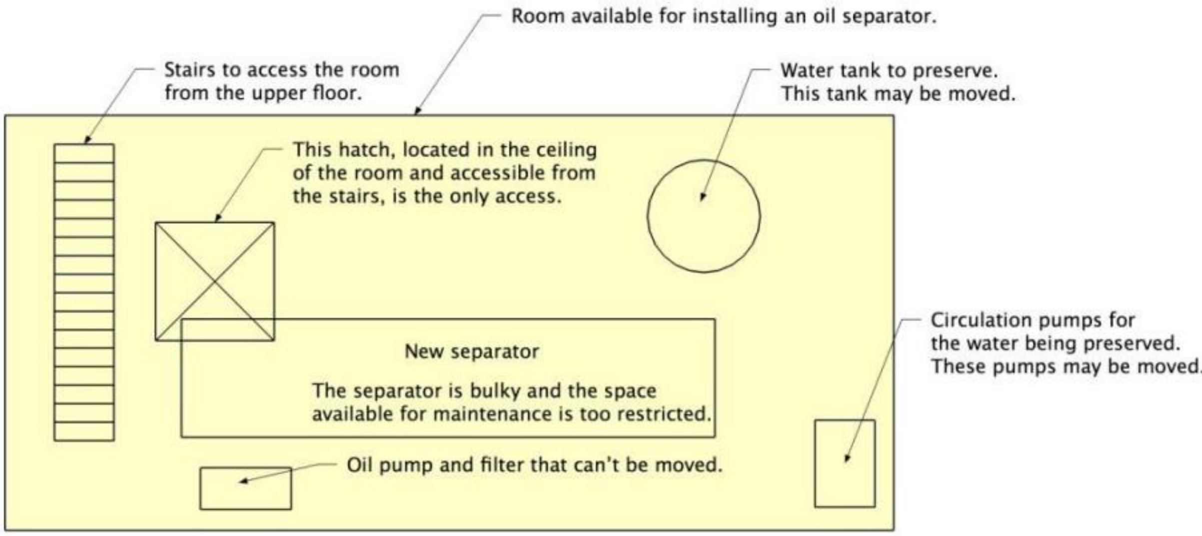
   b) Dismantling one of the pipes freed a trench and a rectangular crossover located in a concrete block connecting the two levels mentioned previously.

   c) This crossover allowed a new 6-inch pipe to be installed without the need to drill through or break up any concrete.

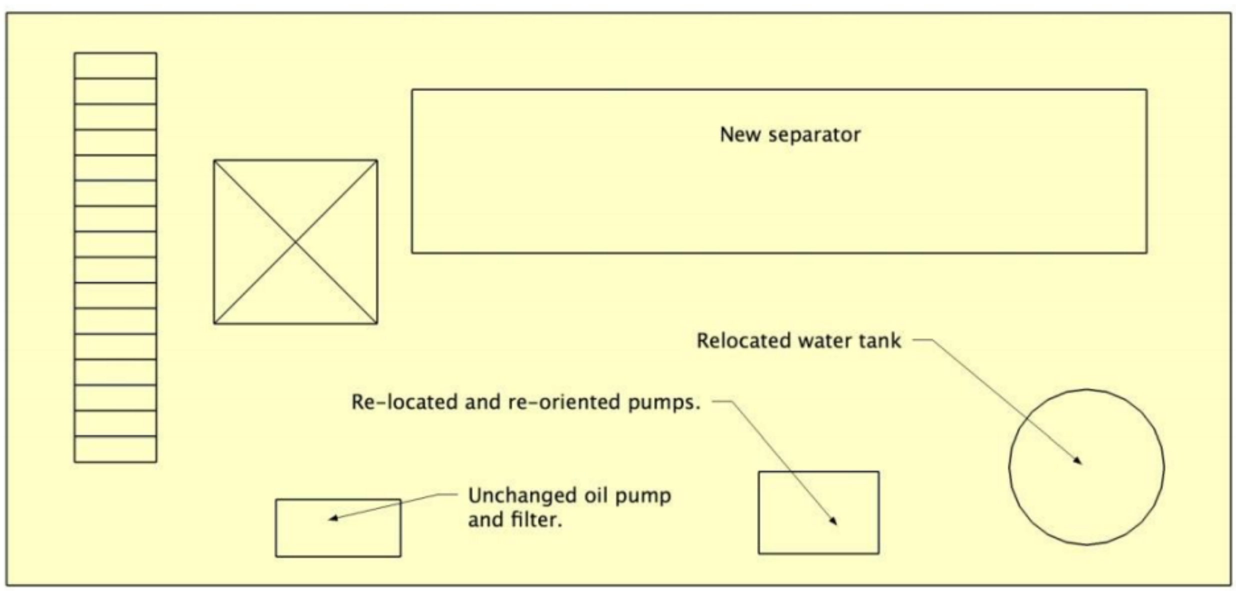
Challenge: Equipment with some assembly required

1. Problem: A new oil separator needed to be installed at the generating station. The only room available did not have enough space to hold the separator. Furthermore, the only opening available to access this room was too small for a pre-fabricated separator to fit through it.

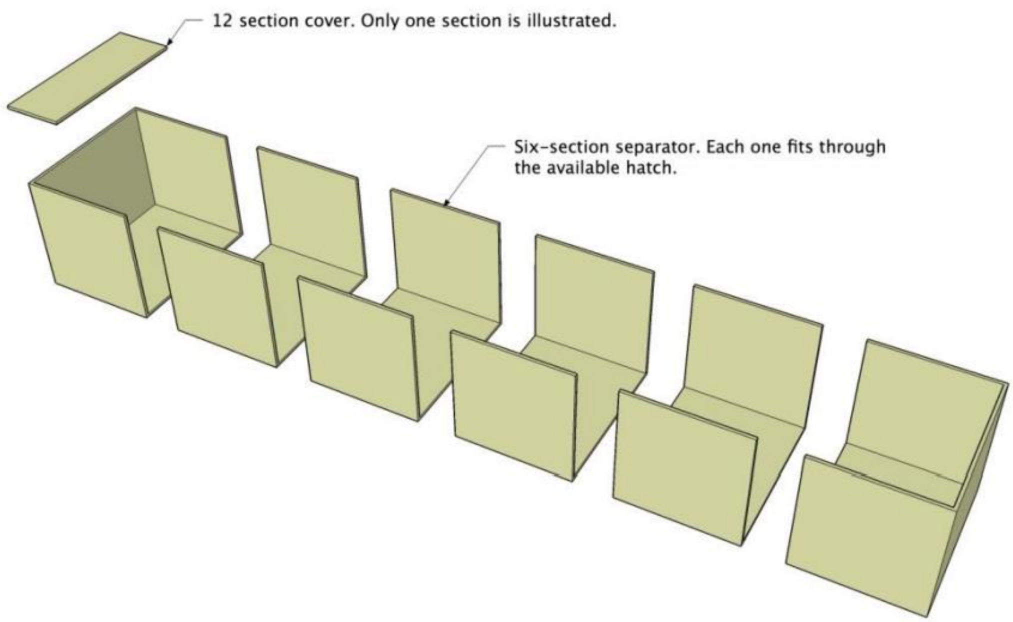
2. Solution: Refer to the sketch below that illustrates the room and the equipment layout prior to the work.



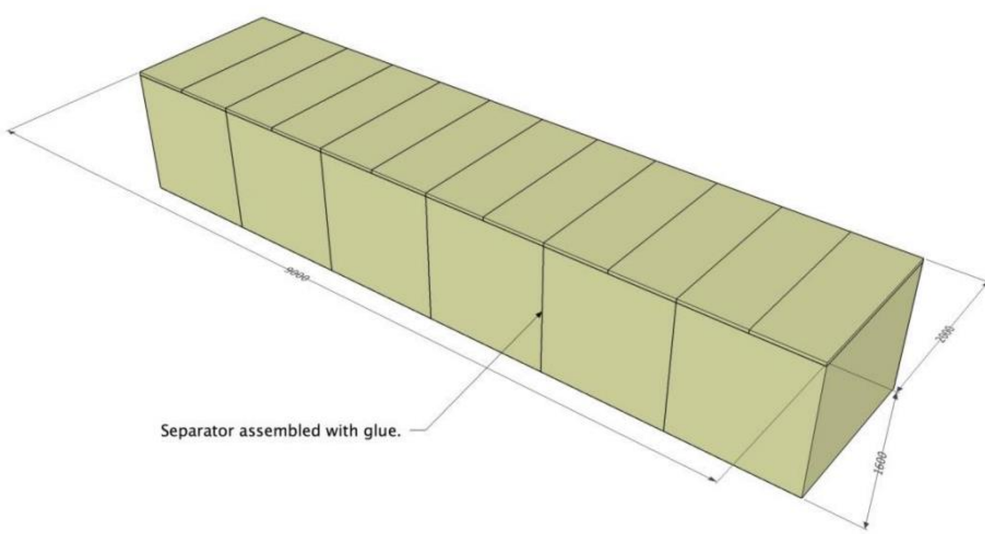
The next sketch shows how the room was re-configured to free up enough space to accommodate the new separator.



The separator was built in sections small enough to fit through the available opening, as shown in the sketch below:

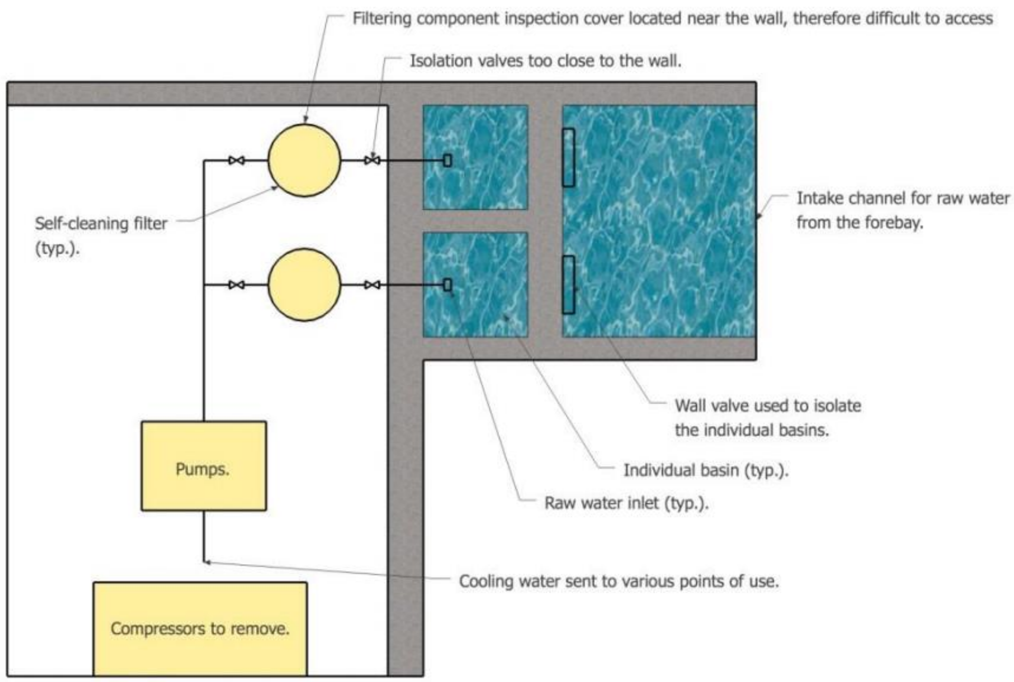


Since the separator was made of fibre-reinforced plastic (FRP), it was simply glued together in its final location.

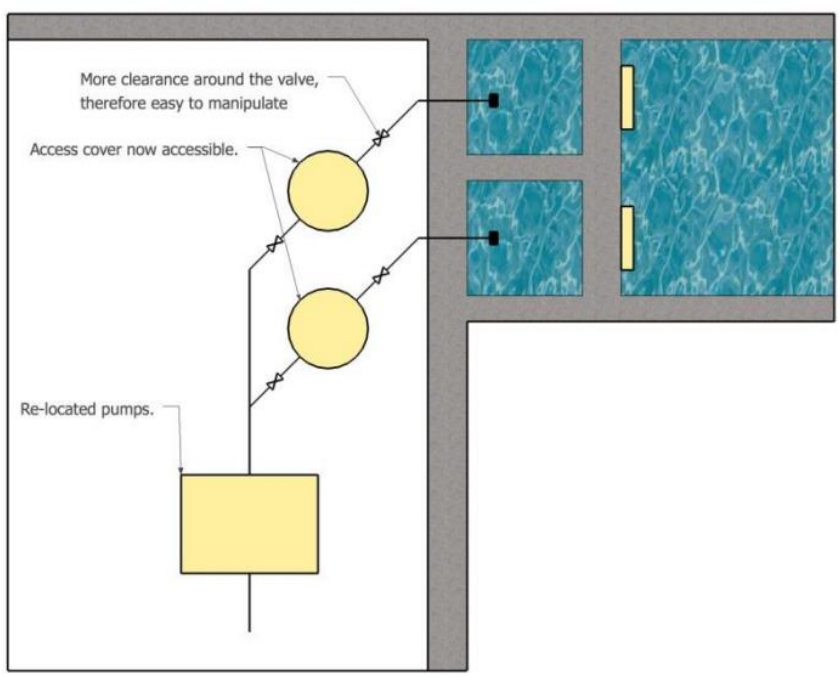


Challenge: Repositioning equipment

1. Problem: Two self-cleaning filters were in a location that made it difficult to maintain the other filter components. Furthermore, two isolation valves were also in a location that made it difficult to manipulate them.
2. Solution: Refer to the sketch below illustrating the equipment's initial position:



The following sketch illustrates the proposed layout:



Challenge: Increase turbine-generator unit capacity.

1. Problem: Increase the number of megawatts produced by a generator.
2. Solution:
   a) Re-build the generator using modern materials that reduce electrical losses.
   b) Use a new turbine with fully-optimized blade profiles.
   c) Modify the penstock profiles to reduce hydraulic load losses; for example, the draft tube diffuser could be optimized by modifying the wall curvatures to minimize losses caused by friction and turbulence.

Optimizing the turbines and penstocks became an option thanks to powerful new software that could perform calculations that were previously impractical because they took too long.

Another aspect that had to be taken into account was the fact that an increase in power almost always results in an increase in the balance of plant systems connected to the turbine-generator unit. However, even though efficiency is maximized, an increase in capacity would have the following repercussions:

- Increased thermal losses;
- Increased demand for cooling the generator's stator;
- Impact on braking and regulation systems:
  - Increased compressed air volume required to feed the braking system;
  - Increased compressed air volume required to feed the regulators' air-over-hydraulic tanks;
  - Increased volume of hydraulic oil.

All of these systems must therefore be modified or, in certain cases, completely replaced.

Benefits of the Solution

The primary advantages of the aforementioned solutions are:

1. **Minimal disruption of operations**

   By using modular equipment and pre-assembled sections of piping, it was possible to decrease the amount of time required to perform the work as well as unit or generating station shutdown times. Installing temporary piping and equipment also helped to mitigate the impact on generation.

2. **Improved operating conditions**

   A concerted effort was made to propose layouts that were as functional as possible, correcting certain deficiencies on the plans with regard to equipment accessibility and operation of certain valves.

3. **Decrease in forecasted refurbishment costs**

   The proposed solutions aimed to optimize layouts so that they would not only be as functional as possible, but also the least expensive possible. The decrease in shutdowns of generating stations and units, mentioned as the first advantage, also results in reducing generation losses, thereby decreasing overall project costs.

Difficulties

The most significant difficulties encountered during generating station refurbishment are:

- Limits imposed for generating station or unit shutdowns;
- Impossibility of manipulating certain components such as valves and gates;
- Environmental problems tied to the presence of certain materials used in the past, such as asbestosbased insulation and lead-based paint.

Conclusion

The key point to retain from this white paper is that the issues associated with generating station production must be properly understood and taken into account when solutions are developed. When planning the work, the units' shutdown schedule must also be taken into consideration. The challenge lies in finding simple and economic solutions that ensure operating staff safety, high equipment reliability, minimal maintenance, and long-term operability of the new facilities.

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