FMHL+ : Power extension of the existing Hongrin-Léman powerplant: From the first idea to the first kWh

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Introduction

FMHL (Forces Motrices Hongrin-Léman SA) is the Owner company and belongs to the shareholders Romande Energie SA, Alpiq Suisse SA, Group-E SA and City of Lausanne. Alpiq Suisse SA, as Owner representative, is the company in charge of supervising the study and implementing the new FMHL+ project. Hydro Exploitation SA, as operator of FMHL, would operate the new power plant FMHL+.

The FMHL+ project consists of expanding the capacity of the existing Hongrin-Léman Power Plant in Switzerland, a 240 MW pumped-storage plant built in the early seventies, by providing an additional capacity of 240 MW.

The new underground power plant is integrated into the existing waterways between the Hongrin upper storage lake, (with a capacity of around 52 million of cubic meters at an altitude of 1255 m.a.s.l) and the lake Geneva (lake Léman at around 372 m.a.s.l), mainly by connecting into the existing penstock and tailrace. It will add 240 MW (including 60 MW as reserve) of additional pumping and turbining capacity to the existing 4x60 MW ternary units of the existing power plant. This will be achieved by installing two new 120 MW ternary units each in a new cavern.

This paper presents the development of the studies and the project and is organised as follow: (i) project description and major challenges, (ii) specific study related to the area and constraints, (iii) machinery arrangement and transient analysis related to the existing scheme, (iv) ongoing commissioning and finishing works.

1. Project description

The increasing amount of new renewable energy sources (mainly solar and wind energy) in Europe requires higher amounts of storage capacity and flexibility for the networks. One of the most efficient methods of grid regulation and energy storage is still the use of pumped-storage plants. In order to be prepared for future tasks, FMHL decided to expand the capacity of the Veytaux pump-storage scheme in 2007. Figure 1 shows the position of the production site at lake Geneva near the city of Montreux and the general layout of the scheme.

Figure 1. General location of the FMHL pumped-storage plant; right, general layout; left, in red, new power station

1.1 Existing Veytaux I Power Plant

The existing Hongrin-Léman pumped-storage plant, located in Western Switzerland (Figure 1), commissioned in 1971 and operated by FMHL, exploits a maximum head of 878 m between the upper Hongrin Reservoir (52 Mio m^3 at 1255 m a.s.l.) and the lake Geneva (89'000 Mio m^3 at 372 m a.s.l.) at the existing underground powerhouse (Veytaux 1). The Hongrin Reservoir is formed by a twin arch dam of 125 and 90 m height respectively (Figure 2 left).

The existing powerhouse contains four horizontal axis pump-turbine units with a total installed power of 240 MW (Figure 2, right). During off-peak periods, water from lake Geneva is pumped at a maximum rate of 24 m^3/s to be turbined during periods of high demand with a discharge up to 32 m^3/s. The connection between the existing powerhouse and lake Geneva is made by a 200 m long underground straight free surface channel.


Figure 2. Hongrin Reservoir with the twin arch dam (left) and view of the existing 140 m long Veytaux 1 Powerhouse (right).

1.2 FMHL+ project extension

The objective of the FMHL+ enhancement project is to double today's plant capacity by constructing a new underground cavern adjacent to the existing one at Veytaux (Figure 3) and to procure regulation energy both in turbine and pumping mode thanks to a special function called "hydraulic short circuit mode". Two additional vertical axis pump/turbine groups of 120 MW each will be installed. The total power capacity will be 480 MW, with 420 MW as normal operating mode, and 60 MW left as reserve. The increased flexibility enabling peak electricity generation will allow the plant to play an important role in supplying electricity to Western Switzerland and in meeting the growing demand for balancing energy, which is mainly due to the extension of new renewable energies in Europe and Switzerland.

The new plant (Veytaux 2, Figure 3) will mainly use the existing upstream waterway (headrace tunnel and penstock) and downstream hydraulic system (tailrace channel and water intake). The existing 8 km long headrace tunnel and the 1.4 km long pressure shaft have both enough capacity to transfer the new generating and pumping discharges of 57 and 43 m^3/s, respectively. The new hydro and electro-mechanical equipment is installed in a underground cavern with the following dimensions : 100 m long x 25 m wide x 56 m high. The main cavern, as well as the galleries, were excavated using traditional drill and blast method. The total excavated material of the main cavern is of about 94'000 m^3, while the total scheme in Veytaux represents 150'000 m^3 (430'000 t) with a total concrete volume around 30'000 m^3.

On top of that, the transient calculations of the upgraded scheme have shown that the volume of the existing surge tank will be deficient regarding water mass oscillation. Therefore, a new surge shaft of about 170 m height and 7.2 m internal diameter needs to be built at the upstream end of the pressure shaft slightly upstream of the existing one. It will be connected to the headrace tunnel by means of a 28.5 m long tunnel with an internal diameter of 2.2 m.

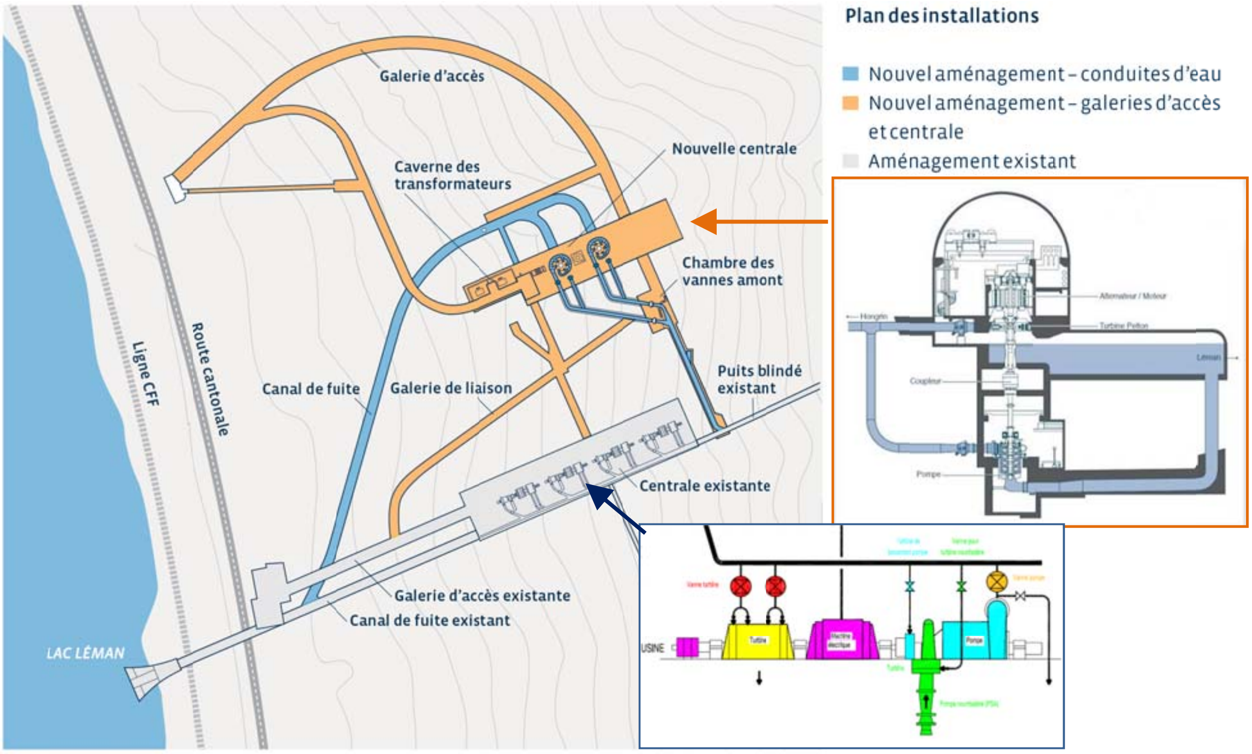

Fig. 3. General layout of both existing Veytaux I (grey) and future FMHL+ powerhouses (Veytaux 2; in blue, new waterway and in orange, new galleries and cavern).

1.3 Major challenges of the new project

The major challenges for building this new power plant FMHL+ connected to an existing waterway were:

- Carrying out construction in a dense urban area close to structures and buildings such as highway bridges, international railway, a historic castle and a main national road.
- Maintaining the existing Veytaux 1 hydraulic schemes and Veytaux 1 power plant in full operation during the erection of the new project. Particular attention was paid when doing the connection from the extension project to the existing waterways, reducing as much as possible the power production stoppage.
- Selection of the machinery arrangement in relation with transient analysis and overpressure to suit the existing pressure shaft characteristics (safety).

In order to reach these challenges, specific studies were done to obtain a positive answer for the acceptance of the project in a dense and complex neighbourhood (Chapter 2).

The fact that an important FMHL+ advantage was "not building a new waterway" determined choices regarding the selection of the machinery arrangement (Chapter 3).

2. Specific studies related to the area and the existing constraints

2.1 Geological and hydrogeological studies

Geological studies

In order to determine the geological conditions, some classic geological surveys were undertaken in 2008. A dozen boreholes were made around the existing power plant in order to confirm the quality of limestone rocks on both sides of the existing power plant as well as its geomechanical characteristics and permeability.

At the same time some hydrofrac stress measurements were undertaken to determine the existing stress of the rocks to decide the new cavern orientation. At the site stress measurement showed also that an orientation parallel to the former power plant was more suitable to minimize the stress in the rock and to benefit from the arch effect of the main cavern.

While geological surveys were possible around the existing power plant in Veytaux, the geological environment of the new surge tank could not be investigated since it was located in a water springs protected area which forbade any works without specific authorisation. Therefore no boreholes could be undertaken in this area before obtaining final acceptance for the project by the authorities.

Hydrogeological studies

The vertical arrangement of the ternary units (Figure 3) with the pump located 25 m under the water level of the lake Geneva led to the creation of an impermeable curtain around the new cavern. During 2008 investigation, tests were performed using three piezometers to assess rocks natural permeability.

The largest hydrogeological concern was located 1000 m above the power plant in the area of the new surge tank which is located in a water springs protected area. The hydrogeological studies carried out by FMHL show a small risk of sediment pollution of the spring water due to underground flow. In order to mitigate this risk and to prevent any water leaks flowing from the gallery or surge tank to the underground environment, FMHL decided to put a steel liner over the new surge tank and connection gallery. As this area has a national interest for drinkable water, the hydrogeological studies and its results were discussed with the representatives of the local authorities (canton Vaud) as well as with national authorities (Minister of Environment and Minister of Energy) in Bern.

In addition, FMHL made a special convention with the owner of the springs to compensate for any damages. During works very up-to-date protection systems were adopted, such as using a double bottom storage tank as well as designating a restricted area to stock and unload oil and gasoil.

2.2 Transportation studies – Impact on the local traffic

The existing scheme in Veytaux is located in a dense urban area with a national road crossing in front of the power plant access. Building such a big project in this urban area implied a lot of transport movements. An amount of around 20’000 truckloads was first estimated with a frequency of 70 trucks per day with a peak value of 120 trucks per day. The excavated rock as well as the concrete material represented the major quantities of these transports. In addition, hydro and electro-mechanical equipments were also delivered on site by oversize transports with occasional frequency.

In order to convince local authorities of the low impact of siteworks on road traffic, FMHL studied two transportation options (Figure 4). The first option weighed the possibility of taking out the excavated rock through the lake. This study anticipated a conveyor belt going above the road, a railway and a pier to load rocks into boats; rocks which subsequently would be dropped off into the lake Geneva to fill holes in a pre-excavated underwater area. Another option was to take rocks out through the railway system (Figure 4).

The second option evaluated the transportation of excavated rocks trough the domestic road network by means of 40 t capacity trucks (Figure 4).

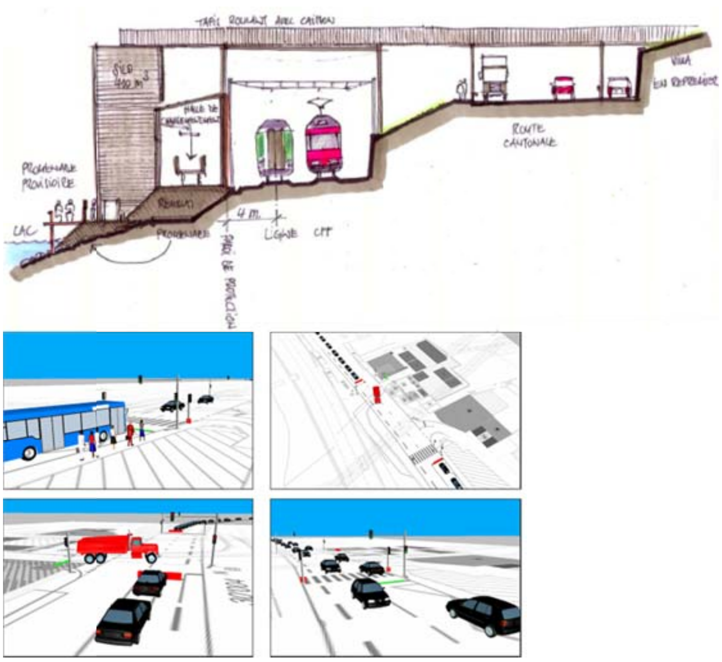

Fig. 4. Evacuation of the excavated material: railway option (l), road option computer traffic simulation (r)

The road option was finally chosen since a transportation computer simulation showed that a peak of 120 trucks per day to transport the excavated rocks would have a limited impact on the existing traffic. Also a waiting zone for the truck and a traffic light were the preferred options against a new on purpose made round-about for the trucks to get into the traffic. The effect of site works on traffic was estimated to represent an increase of 0.5 %.

All the excavated rocks were taken to Carriere Arvel SA, a quarry located 4.2 km from the site works. Excavated rocks were crushed and transformed in gravel and sand as much as possible to produce concrete for works on the power plant. The remainder was used by Carriere Arvel SA for other site works.

2.3 Vibration studies to nearby infrastructures: highway, railway and power plant

Building the cavern and galleries near the operating power plant as well as near pillars of highway bridge supporting heavy traffic was also a major challenge.

In the late sixties, when the current power plant was built, the construction works of the highway bridge were under way. In 2008 the vibration upon highway bridge pillars due to drill and blast excavation method was a challenge. Due to rock hardness no other means of excavation was possible.

Investigations

Specials investigations such as exploratory excavation works with different drill and blast method were made to evaluate, measure and minimize the impact of drill and blast excavation onto the foundation of the existing highway bridge and on the existing power plant.

Already in 2008, a total of 7 explosive exploratory works were undertaken in a gallery located progressively from 50 to 15 m off the foundation of the pillars as well as from the power plant. The vibration generated by these exploratory works were registered and analysed by geologists and by a team of structural experts. These investigations were also communicated and discussed with representatives of the highway infrastructure. The results permitted to conclude that the drill and blast method was feasible. During excavation works, recommendations and a monitoring system were implemented to register, verify and communicate the generated vibrations. Based on these intensive exploratory works and discussions with expert representatives of the highway owner, an agreement was signed with the highway owner before the acceptance procedure.

Monitoring system during site works and defined limits

A monitoring system made by a network of vibration sensors placed at the foundation of the bridge, in the bridge deck as well as in the existing power plant close to equipment was set up (Figure 5). All these sensors were connected to a central unit and the vibration measurements were sent “live” by cellular network to experts in charge of the analysis of this vibration. After each blast this monitoring system allowed the engineer to adjust drill and blast method if necessary.

As for the highway structure, an agreement with the highway owner representative established an acceptable vibration speed of 6 mm/s with a frequency under 60 Hz as information value.

With respect to Swiss norms the absolute maximum value was defined at 12 mm/s with a frequency under 60 Hz.

On site, adjusted blasting patterns were used to limit the vibration. For each borehole, a charge of 4.2 kg of blasting material permitted to stay under the value of 6 mm/s. Additionally, if needed, mining boreholes were also reduced from 3 to 1.5 m long and in some special cases, section of excavation front was executed in 2 stages.

The preparations (exploratory works and agreements performed with the highway representative) made before beginning excavation works allowed safe execution with no major constraints. During excavating works only a few vibration measures reached the allowed speed of 6 mm/s, however these were far from the maximum absolute value.

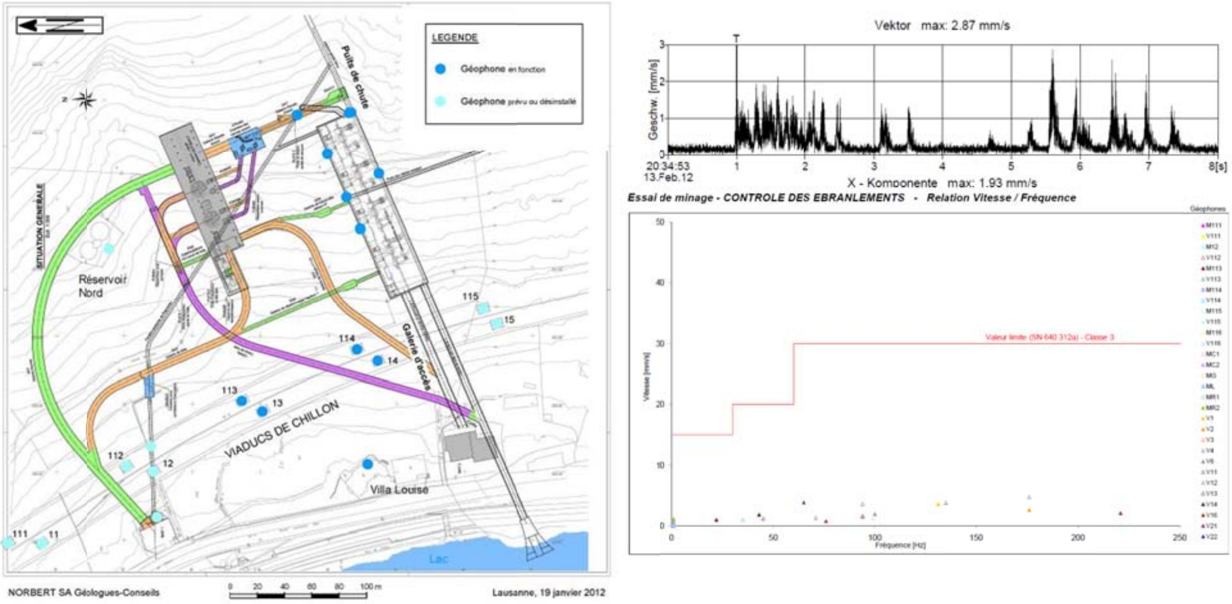

Fig 5. Monitoring system locations indicated by blue dots (l), vibration measurement during blast (r).

2.4 Acceptance of the project by authorities

All the investigation results as well as all the environmental impact assessment were gathered in the environmental report that was part of the acceptance procedure. As a result of all these preliminary studies, exploratory works and intensive discussion with representatives of local authorities, national authorities and environmental associations, FMHL power output extension project was approved with no opposition.

3. Specific study related to the existing scheme

The set-up of the machinery arrangement as well as the power extension taking into account the constraints of the existing scheme was defined by engineers in three phases. This chapter will mainly focus on the choice of the machinery arrangement regarding the transient analysis.

3.1 Phase 1 - Preliminary studies: full technical evaluation of machinery arrangement

The first step focussed on a complete listing of technical solutions analysed under the following parameters:

- Power extension to 180 or 240 MW
- Number of groups from 1 to 4 with power ranging from 240 to 45 MW per group.

A review of all machinery arrangement possibilities was made, such as reversible units (multistage reversible units without power adjustment, mono or two stages reversible pump-turbine with power adjustment), ternary units or separate pumps and turbines in different caverns.

Among the 146 identified solutions, 96 were evaluated as technically feasible. At this stage, the power extension was set to 240 MW in order to offer more operating flexibility in view of the aging of the existing power plant Veytaux 1, which will require refurbish works in a near future.

3.2 Phase 2 - Preselection of more interesting solutions

Among the 96 listed solutions, a multi-criteria analysis results in a selection of 11 solutions that would offer the best profitability ratio with respect to the overpressure criteria of the already-in-use pressure shaft.

Technical discussions with the principal suppliers of equipment were done at this stage, as well as technical visits of existing schemes.

Figure 6 shows the selected solutions ranging from one multistage reversible pump turbine of 240 MW to four separated pump and turbine of 90 MW capacity each.

Installed Power			Ternary unit	Separate unit (multistage pump and pelton turbine)	One stage reversible pump-turbine	Two-stages reversible pump turbine		multi-stages reversible pump turbine
			power adjustment with short circuit operation			no-adjustment	variable speed	without power adjustement
	180 MW	1x180	temporarily discarded	temporarily discarded	Too high gross head	temporarily discarded		dewatering for start up sequence
		2x90	2GT90	4GS90		too severe transient analysis		
		3x60	3GT60	too many units				
		4x45	too low efficiency					
	240 MW	1x240	1GT240	2GS240		1GR 240	1 GRV 240	
		2x120	2GT120	4GS120		temporarily discarded		2 GRM 120
		3x80	temporarily discarded	too many units		too severe transient analysis		
		4x60	4GT60					

Figure 6. Matrix of feasible possibility for the extension project.

3.3 Phase 3 - Selection of the best solution regarding transient analysis

Among the 11 feasible solutions previously identified, the main criteria to determine the best solution, above profitability, was the fitting with the requirement of the already designed and in use pressure shaft. The overpressure limits of the pressure shaft are determined as follow :

Case	Description operation	Limits	Goal
Normal case	Normal shutdown	106%	104%
Exceptionnal case	Emergency shutdown	115%	109%
Accidental case	Degraded operation	115%	115%

Figure 7. Overpressure criteria of the existing pressure shaft in percentage of static load.

For an accuracy approach, transient analysis had to be done with up to date data (i.e. the exact S-curve of the pump or Francis turbine) to evaluate the overpressure for the defined cases (Figure 7).

The main suppliers of equipment were contacted to feed the computer simulation with the characteristics of their equipment. As far as knowhow of supplier equipment is concerned for this data, FMHL had to sign confidentially agreements with each supplier and requested the support of the LMH (Laboratory for Hydraulique Machinery at EPFL) for this critical phase.

The results of this transient analysis showed that the two-stage reversible unit generated an overpressure ranging to 18% for exceptional cases and up to 30% for accidental cases. All the other solutions fitted in the required criteria of overpressure. Thanks to this transient analysis combined with operational criteria such as maintainability as well as services provided to the electrical grid, FMHL finally implemented a ternary arrangement unit of 120 MW composed of a Pelton turbine and a 5-stage-pump.

4. On-going commissioning and finishing works

The main milestones of the works are described as follows :

- site works started on March 7th 2011,
- excavation works were completed by January 31th 2014 (Figure 8),
- concreting and installation of embedded part ended in October 2014 (Figures 8 & 9),
- hydro-mechanical equipment was installed in the cavern from October 2014 to September 2015 and electro-mechanical works started in September 2015 (Figures 9 & 10),
- commissioning of the power plant is under way since the end of March 2016, a first synchronization to the grid for the first unit was done on May 25th. This first unit has already delivered its maximum power to the grid amounting 118 MW and produced the first kilowatt-hours. The first operation in pump mode took place on June 23rd. As far as the second unit is concerned, its first synchronization to the grid was done on August 11th 2016.

Finishing and commissioning works are under way and FMHL expects to benefit from this new power capacity by the end of the year. FMHL would like to acknowledge all engineers, suppliers and workers who were involved in the development and delivery of this project.

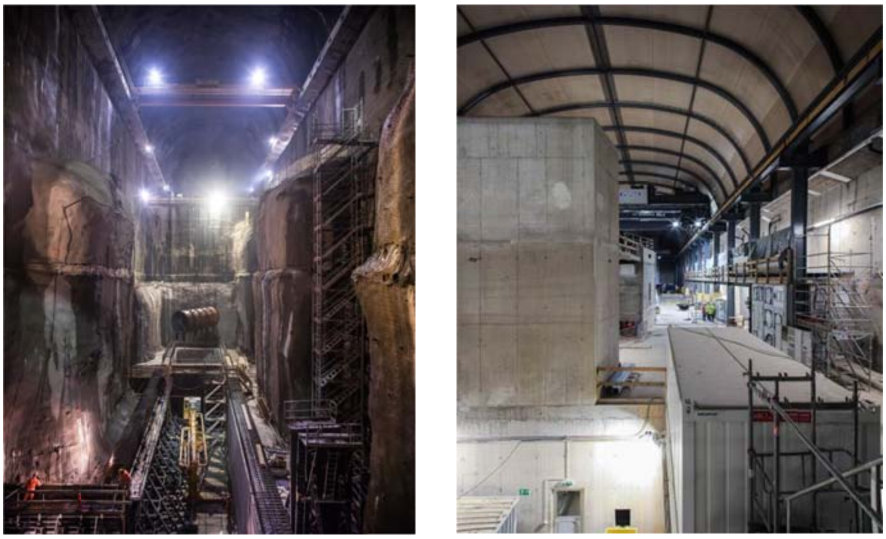

Figure 8. Main cavern : end of excavation Jan. 2014 (l), during commissioning June 2016 (r).

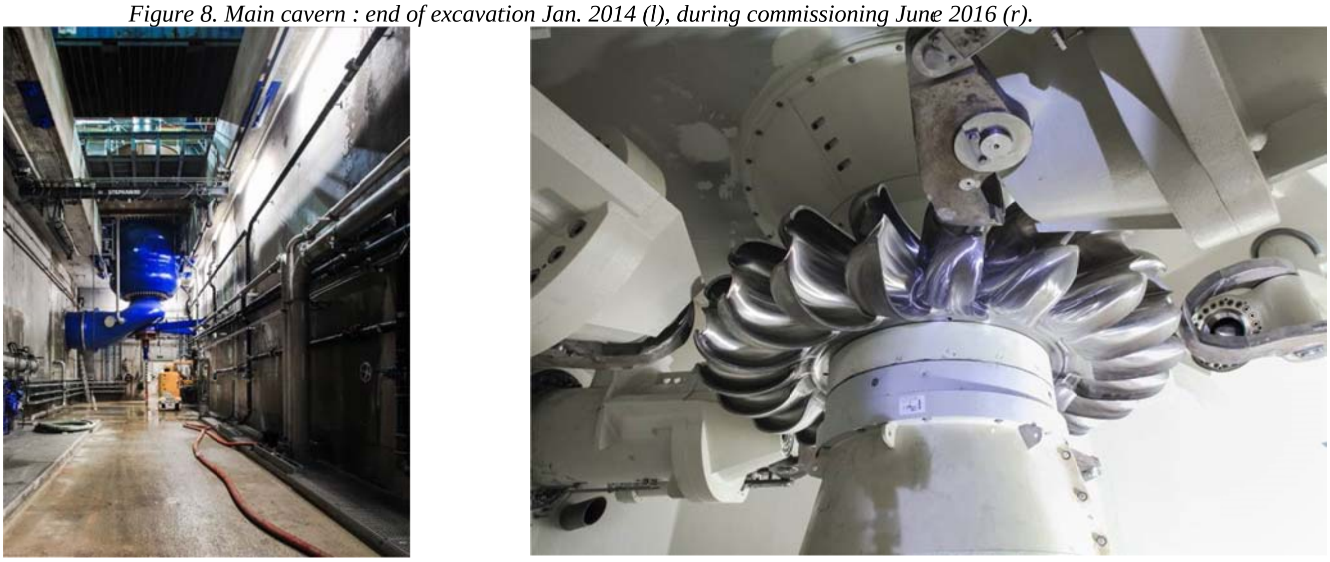

Figure 9. Main hydro-mechanical equipment. Pump (l), Pelton turbine (r).

Figure 10. Main hydro-mechanical equipment Turbine Valve (l), Stator (r).

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