Hydromechanical equipment of the FMHL and extension project of the Veytaux powerplant, Switzerland

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FMHL (Forces Motrices Hongrin-Léman SA) is the Owner's company that 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 the supervision of the study and the implementation of the new FMHL+ project.

The FMHL+ project consists of an extension of the existing Hongrin-Léman powerplant in Switzerland (or also Veytaux 1 powerplant), a 240 MW pumped storage built in the early seventies, by providing an additional capacity of 240 MW, using 2 new ternary pump-turbine units.

The new underground powerplant will be integrated in the existing waterways between the Hongrin upper storage lake, (with a capacity of around 52 millons of cubic meters at an altitude of 1255 m , and the lower Léman lake at around 372m), principally by connecting into the existing penstock and tailrace. It will add 180 MW of additional pumping and turbining capacity to the existing 4x60 MW ternary units of the original Veytaux powerplant with the implementation of two new ternary units of 120 MW each in a new cavern.

The main choice of the new hydro-mechanical equipment will be described below, including the technical justification of the ternary unit layout and the associated impact on cavern design and civil works.

The main design features of each ternary unit includes a very long vertical shaftline (38 m) connecting a motor-generator to a special 5-jets Pelton turbine, and a multistage storage pump with 5-stages, mechanical coupler, as well as associated spherical valves.

An overview of the specific features of the ternary units include operation of separate turbines and pumps used with mechanical coupler, both for conventional generation and pumping and also hydraulic short circuit operation. Numerous technical challenges arise from the use of such a very long shaft line design, and waterways steady and transient hydraulic operation.

The current progress of the equipment design and manufacturing will be presented.

1. Hongrin-Léman project description

The increasing amount of new renewable energy sources (mainly solar and wind energy) in energy production in Europe requires also higher amounts of storage capacity and flexibility of 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 the future tasks, FMHL decided to extend capacity of the Veytaux pump-storage scheme in 2007. Figure 1 shows the position of the production site at lake Leman 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 (red: new power station)

1.1 Existing Veytaux I powerplant

The existing Hongrin-Léman pumped-storage scheme, 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 Lake Leman (89'000 Mio m^3 at 372 m a.s.l.) at the Veytaux 1 underground powerhouse. The Hongrin Reservoir is formed by a twin arch dam of 125 m 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 Leman 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 Leman is made by a 200 m long underground straight free surface channel.

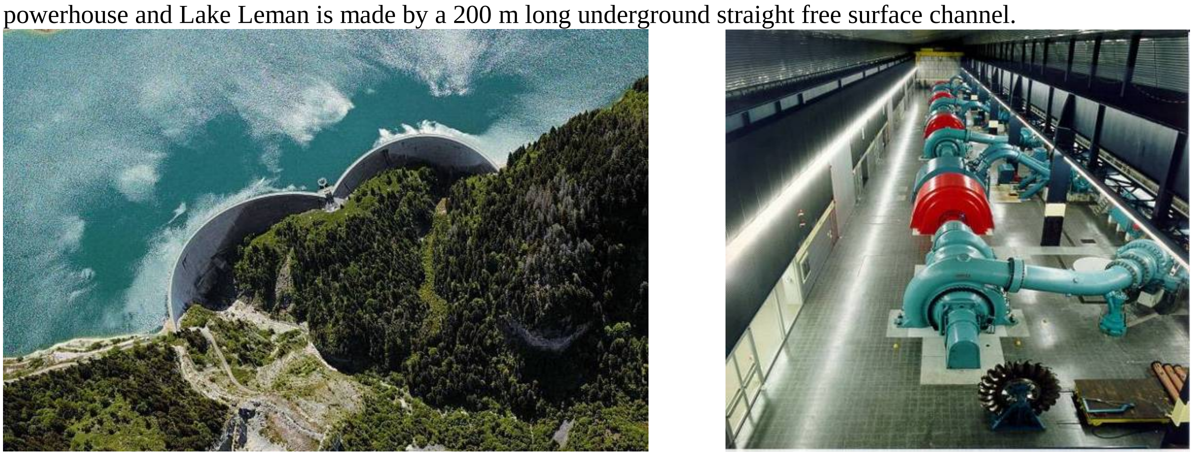

Figure 2: Hongrin Reservoir with the twin arch dam (left) and view of the existing 140 m long Veytaux 1 powerhouse (right)

1.2 FMHL+ extension project

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 special function designed in 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 as reserve. The increased flexibility, generating peak electricity, will allow the plant to play an important role in supplying electricity to Western Switzerland and 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 will mainly use the existing upstream (headrace tunnel and penstock) and downstream (tailrace channel and intake/outlet work) hydraulic system. The existing 8 km-long headrace tunnel and the 1.4 km-long pressure shaft have both enough capacity to transfer the new generation and pumping discharges of 57 m^3/s and 43 m^3/s, respectively. Nevertheless, the transient calculations of the upgraded scheme have shown that the volume of the exiting surge tank will be deficient regarding the water mass oscillation. Therefore, a new surge shaft of about 170 m length and 7.2 m of internal diameter will be constructed at the upstream end of the pressure shaft to the south-east of the existing one. It will be connected to the headrace tunnel by mean of 28.5 m-long tunnel with 2.2 m of internal diameter (see also Fig.5). Figure 3, below, shows the shared downstream channel system which was enlarged on the common part.

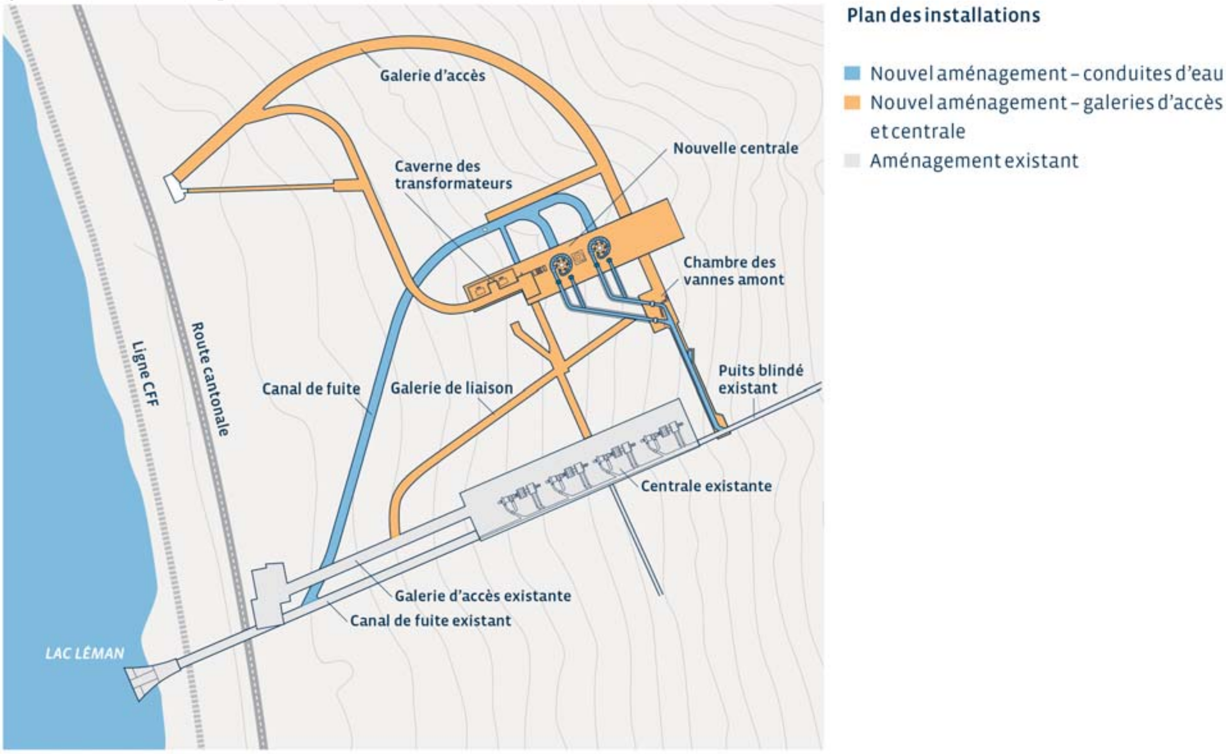

Fig. 3. General layout of both existing Veytaux I (grey) and future FMHL+ powerhouses (in blue new waterway and in orange new galleries and cavern)

2. Main choices for the ternary unit concept

GILHEM group was appointed by the Owners representative as Engineer for the project. GIHLEM (**G**roupement d'**I**ngénieurs pour le projet de suréquipement de l'aménagement **H**ongrin-**LEM**an) comprises the three following engineering and design Consultancy firms: STUCKY SA (leader), EDF-CIH and EMCH+BERGER. The scope of work included both the electromechanical and civil engineering with a mandate covering all stages from basic design up to equipment specification, bidding, project execution and final commissioning of the plant.

Detailed preliminary studies were first carried out; this chapter will summarise the study and design process that has led to the final choice of two ternary units of 120 MW for the FMHL+ hydro-mechanical equipment.
It is based mainly on three steps described below, which have lasted 3 years, starting from the first feasibility studies up to the signing of main equipment Contracts with hydro-mechanical manufacturers.

2.1 Feasability stage

First preliminary design studies were started in 2007, showing that an increase of around 180 MW of the existing 240 MW power capacity was considered as technically and economically feasible at the scheme.

Starting in July 2008, EDF and ALPIQ first worked on a preliminary study based on multi-criteria analysis. The purpose was to identify suitable power plant configurations involving all types of units technically available, and to make an economical analysis of the most adapted solutions based on the given project criteria.

The main constraints taken into account were the adaptation limitations of the existing waterways, the size of the machines and the setting needed with the new underground cavern construction, and the overall operational flexibility benefits of the plant. Following discussions with the Owner, additional criteria such as maintainability and service provided to the electrical grid were also defined in order to evaluate the various configurations with the most accurate method.

From an initial matrix of more than 60 possible machine configurations, including two stages plants and use of multistage reversible units, ternary units or separate pumps and turbines, the multi-criteria analysis was concluded in February 2009. The chosen technical solution was a new powerplant to be based on two vertical ternary units, each of around 120 MW capacity, each ternary unit including one Pelton turbine and one multistage stage storage pump fitted with a mechanical coupler.

2.2 Basic design stage

Basic design studies were then carried out by GILHEM with the Owners representatives in 2009. This included key aspects of equipment selection with preliminary dimensioning, assessment of sub-configurations aspects, ancillary options, preferred bearing arrangements, shaft seal types, etc, and consideration of other principal design issues in order to optimise the final equipment specification. This stage was also structured in a way which included technical briefings and obtaining feedback from potential hydropower equipment suppliers, prior to the tendering stage. During year 2010, a detailed set of technical specifications was prepared for the 2 ternary units, including auxiliary power station equipment and 6 spherical valves.

The design of ternary units would need a total unit shaftline of around 38 m, fitted with motor/generator, Pelton turbine and multistage storage pump in vertical shaft arrangement from top to bottom. For the net heads expected over 900 m, the use of 5-stage storage pumps was selected. This ternary unit layout is relatively unique in terms of size and unusual machine configuration compared to current worldwide experience of other pump storage machines.

2.3 Tender stage and Contract awarding

The tendering and evaluation stage was carried out at the end of 2010 with the final contract awarding of main hydro-mechanical equipment lots held in early 2011. Main ternary equipment suppliers appointed included: ANDRITZ HYDRO for the 2 motor-generators, Pelton turbines and ancillaries, and a consortium of ANDRITZ HYDRO/d2fc energy valves for the 6 spherical valves, pipes and ancillaries, and VOITH HYDO for the 2 multistage pumps, suction gates and other pump ancillaries. Engineering design approvals of all hydro-mechanical equipment has been managed throughout by GIHLEM specialists with Owner's representatives. VOITH HYDRO was also given responsibility to perform a complete hydraulic transient analysis study of the overall scheme, and ANDRITZ HYDRO performed the overall rotordynamic shaftline analyses of the ternary unit including flexion (lateral) and torsional analyses.

3. Technical features of the chosen equipment

The unit arrangement adopted is based on a classical ternary vertical unit layout, including from top-to-bottom, a generator-motor, a Pelton turbine, a mechanical coupler and a storage pump, as shown on the cross section view of the FMHL+ powerplant, see Fig. 4 below. Associated spherical inlet & discharge valves and pump suction gate are shown also. Naturally, the storage pump is placed at the lowest feasible point, principally due to the cavitation requirements. The turbine placement was adapted to suit discharge outflows at tailrace level.

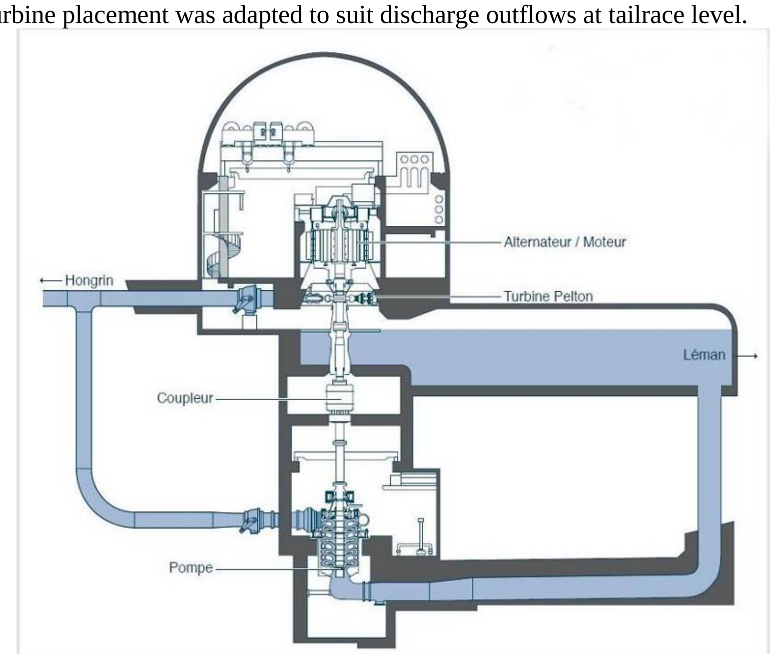

Fig. 4. Cross sectional view of the ternary unit

3.1 Unit shaft arrangement

Design studies confirmed that the principle of a ternary arrangement could be used, and a number of feasible shaft connection and bearing arrangements were also considered. The total vertical shaftline length of each ternary unit is relatively long, at over 38.0 m. Each ternary unit is provided with two thrust bearings, one for the generator-motor/turbine section, and the other for the storage pump, along with a number of intermediary guide bearings. Advantages of upper-located thrust bearing were adopted, including thrust bearing designs combined with upper guide bearings. Shaft design with rotor masses, bearing locations and bearing stiffnesses were adopted in order to control and achieve good overall shaftline rotordynamic characteristics accordingly.

3.2 Turbine

The turbine is located below the generator-motor, which includes the upper thrust bearing, resting on the upper bracket. The 118,8 MW Pelton turbine is a state of the art 5 jets unit with specific features related to the ternary unit configuration, such as a lower shaft and a lower bearing located in a watertight shaft sleeve going through the turbine pit and associated specific handling and dismantling tooling. The Pelton discharges directly into tailrace at atmospheric pressure.

The turbine is also used as a starter for the storage pump (using nozzles with staged opening), and the runner has to be water-cooled to avoid any overheating during pump operation or synchronous condenser mode.

The hydraulic design of the turbine is based on an existing close reference from the manufacturer ANDRITZ HYDRO and no specific model test was considered needed, leading to significant costs and time saving for the design stage. However extensive model tests were carried out of the tailrace section, [Ref. 3].

3.3 Storage Pumps

Each multistage storage pump is of centrifugal-type, and is of modern “state of the art” design, vertically arranged, consisting of 5-stage impellers (nom. outer dia. 2.2 m) fitted onto a single pump rotor, housed within an outer array of integrally vaned return diffuser stages accordingly. The last (top) stage impeller discharges through a diffuser vane into the spiral volute casing, from where pump discharges back up the penstock via connected outlet pipe and discharge valve. The overall pump casing is supplied in just two main sections; with main pump body bolted directly to the spiral casing stay vane type of design. The pump rotor is connected to mechanical coupler unit above by intermediary shaft, via top mounted pump thrust bearing. The pump intake passage at the bottom consists of 90 degrees elbow-bend which connects with pump suction gate situated further along the intake passage liner. The entire pump unit is of non-embedded (open) type, supported with bolted feet on foundation supports within the powerhouse, with pump dismantling done with special rails and crane.

The storage pump units operate at fixed speed of 500 rev/min, each with the following rated operation:

Discharge, Q_r	= 11.7-12.8 m^3/s,
Head range, H_g	= 884.0 m - 837.4 m, (gross head range, maximum and minimum)
Power input, P	= 113.2-116.8 MW in normal operation.

The storage pumps are not governed as such; pumping discharge flows are simply regulated only by the prevailing heads in the waterway system of Hongrin-Leman during operation.

In order to verify the hydraulic characteristics and contract guarantees of the storage pumps, a hydraulic laboratory scale-model test of the unit was successfully carried out by the supplier VOITH HYDRO in Germany during 2011. The tests were done on a reduced model unit with 3 stages rather than 5, and included verification of pump characteristic head-flow curves and other specified parameters. Significant CFD work was performed beforehand by the supplier in order to optimise the final hydraulic design.

The pumps are intended to be operated with high levels of efficiency with relatively wide range of operation. During normal pumping duty, the storage pump units always run at full load, either individually or 2 units together, fully independently, with or without other Veytaux 1 units operating. The pumps are also designed for hydraulic “short-circuit” operation, where a proportion of the pump discharge is diverted back though the Pelton turbine (see later).

Thus a relatively complex set of hydraulic transient conditions are applicable to the entire scheme, arising from numerous different permutations of units operation with different unit types, plus possible transient scenarios. Maximum allowable waterhammer pressures were also limited on the Project, due to existing steel penstocks constraints. Exceptional pumping and turbine flows arising from possible load rejection, runaway conditions and other exceptional conditions were also of special interest, including possible flow reversals. These studies also verified the final operating times required of pump starting with Pelton turbine nozzles, and spherical valves opening/closing characteristics. Extensive hydraulic transient analyses were necessary, including comprehensive study of the complete waterway system for Veytaux 2 (the new powerplant) including Veytaux 1 (the existing powerplant) operation, incorporating hydraulic characteristics of all existing, and new pumps and turbines. See also paper by pump supplier VOITH HYDRO [Ref.5].

3.4 Spherical valves

Each ternary unit is equipped with 3 main spherical valves for isolation purposes, including:-

(i) main inlet valve of the Pelton turbine (MIV),

(ii) pump discharge valve of the storage pump (PDV),

(iii) common inlet valve (CIV), this latter valve being located upstream of both the MIV and PDV at the connection with the penstock bifurcation in separate cavern, and provides added security for the scheme.

The MIV & CIV spherical valves are nominally sized at 1.5 m diameter (the PDV 1.3 m). Each valve serves to enable safe isolation of the equipment for operation and maintenance purposes. The valves closing principle is with penstock pressure water, and for opening function, high pressure oil, with each spherical valve being equipped with its own dedicated HPU oil control system with back up pressure bladders accordingly. Each valve has two dual acting water/oil servomotors, positioned on each side of the valve.

All valve design is of modern "state of the art", and all six valves are similar design, based on use of 2-piece body sections, and single rotor-ball supported by trunnion bearings in the conventional manner. Rotor-ball sealing is of double-seal ring type, with both service seal on the low pressure side, and maintenance seal on high pressure side. Valves are supplied with a set of adjoining connecting pipes to the penstocks with safety-bolted connections. The PDV and CIV valves are of relatively unusual arrangement with horizontally-orientated servomotors to aid compactness within the powerhouse cavern. Operation of the ternary unit valves (turbine, pump) is fully automatic within the power station.

4. Main design challenges

From the previously described unit, a certain number of technical aspects are considered as specific to the FMHL+ unit layout and are therefore briefly described in this chapter.

4.1 Adaptation of the existing waterways

The waterways of the Hongrin-Léman initial project are well adapted to a significant increase of the powerplant discharge, mainly because no additional works are required on the headrace tunnel or the pressure shaft, but a certain number of adaptation works were defined during design stage and are currently under progress.

Further to transient analysis done at early design stage and previous to tender specification release, it was decided to modify the upstream surge tank in order to allow proper and safe operation of the new extended power station.

A 170 m deep surge shaft of 7.2 m diameter is therefore currently excavated and will be connected to the waterways before commissioning of the new FMHL+ powerhouse. It will be connected both to actual headrace channel and existing expansion chamber.

It is to be noted that transient calculations have been done initially by EDF, then confirmed by PVE (Power Vision Engineering, Owner's transient specialist) and finally in the responsibility of the pump manufacturer (see [5]). All simulations, including more than 25 operational cases covering pump, turbine, hydraulic short-circuit modes and operation of both FMHL+ and Veytaux I plants, have shown very close results, even though calculation have been done with different software. This gives very good confidence in the waterways adaptation process, which is considered as a key point for the success of the FMHL+ project.

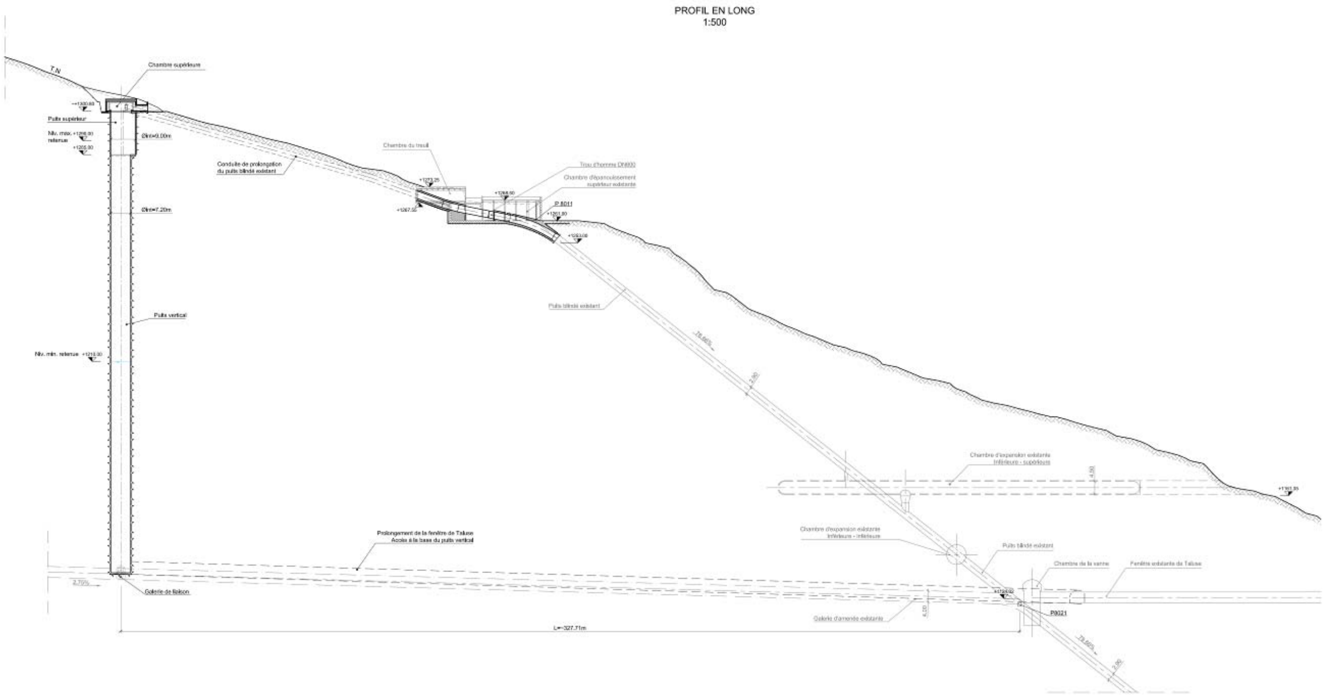

Fig. 5. Cross sectional view of the new upstream waterway layout

Additionally to the upstream waterways transient analysis, the model test done at the Hydraulic Construction Laboratory at EPFL University of Lausanne (EPFL-LCH) (see [4]) has also shown the constraints of the new connecting branch of tailrace tunnel of FMHL+ connected to Veytaux I tailrace. As the impact, mainly for pump operation, was leading to operation limitation, it was decided to additionally deepen the common part of the existing tailrace channel to ensure a constraint free operation of FMHL+ powerplant, whatever the level of Léman lake.

4.2 Hydraulic "short circuit" operation

The main purpose of hydraulic "short circuit" operation is to regulate the pump discharge by using simultaneous operation of the Pelton unit, which can therefore operate in power regulation mode.

Specific CFD studies have been done by the turbine manufacturer in order to evaluate the hydraulic impact of the T-shaped manifold –connecting the high pressure branch of the pump to the turbine inlet on the turbine operation.

A scale-model of the tailrace of the Pelton unit with pump inlet pipe has also been done at the VAW laboratory in Zürich University to evaluate the risk of air admission in the pump during hydraulic short circuit (see [3]).

4.3 Shaft line

As mentioned above, a specificity of large ternary units is their relatively very long shaft line, leading to special technical challenges for both mechanical and civil works design.

The FMHL+ shaft line consist of a total of 6 guide bearings, 2 thrust bearings, 9 shafts, 2 hydraulic machines, 1 generator-motor and 1 mechanical coupler, with a total length of around 38 m from top of unit to pump bottom.

The dynamic shaft analysis was therefore a key design step to validate unit behaviour and safety margins from critical speeds, such as critical bending speed.

The influence of bearing stiffness was considered, as well as rigidity of civil works, mainly on the upper part of unit with the key participation of the generator wall. The critical speed for various operating conditions was verified by manufacturers in Rotordynamic studies. Design requirements included principal need for avoidance of any machine operation near critical frequencies or harmonics identified, including during transient operations.

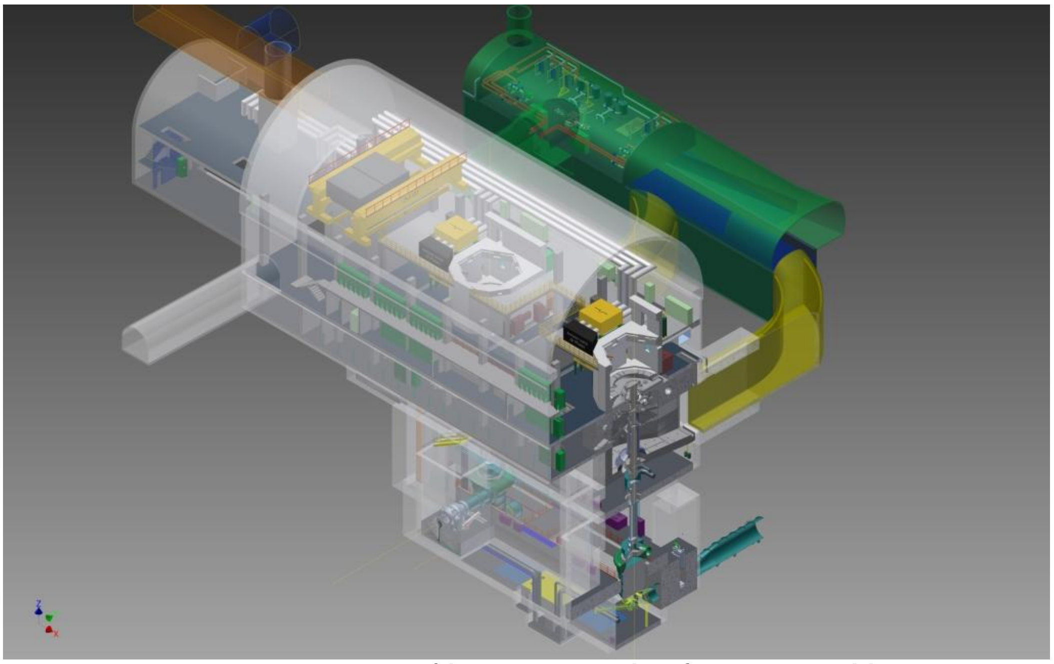

Fig 6. Cross-section view of the FMHL+ powerplant (from EDF 3D model)

Additionally to the above mentioned details, we can also highlight that all the specific equipment related to hydraulic torque converter (HTC), such as anchoring and pipe routing in the cavern, have been considered in the early design phase and these provisional items will be implemented additionally to the supplied mechanical coupling.
If the Owner requires additional increase of unit flexibility in the future, the adaptation and implementation of the HTC will therefore be possible with limited impact on the powerplant.

5. Actual situation of the project

This last chapter gives an overview of the current status of the project and the main target for its achievement.

5.1 Design and manufacturing

The design of most of the main components described in this paper is under finalization.

The hydromechanical equipment is currently in the manufacturing process. Most of the main and heavy parts procurement is already done, main equipment welding and machining process are on the way in various locations, mainly in Europe.

The next milestone will be the factory acceptance test of main equipment, such as spherical inlet valves, turbine runners and nozzles etc...

Pre-assembly and pressure test of key components such as pump fixed and rotating parts will be done in order to mitigate the risks on site assembly works.

5.2 Site works

Civil works is as today in the excavation process of the main cavern. The great challenge to build an underground powerplant very close and below the Léman lake level is ongoing.

Further to a complete shutdown for overaul of both Hongrin dam and Veytaux I powerplant in late spring 2013, the 55 to connecting pipe of the FMHL+ penstock has been inserted on the existing pressure shaft, establishing the first milestone of the hydromechanical works on the project (see Fig.7). It will be connected to the FMHL+ units during the next operation interruption, along with connection of the new upstream works (ie. new surge shaft).

Fig 7. Site pictures of the FMHL+ connecting pipe assembly and welding

The first mechanical activities regarding unit embedded parts should start at the beginning of 2014 and go ahead up to commissioning of the first unit in late 2015.

The erection works, covering 12 lots in total for the electromechanical equipment, will be a very challenging task, with complex coordination and interface works.

Test and commissioning activities will then confirm the high quality and performance level expected for the whole supply of hydromechanical equipment.

Summary

The FMHL+ project is currently at final detailed design stage, with its main hydromechanical equipment consisting of two 120 MW ternary units under manufacturing process.

The very challenging condition for unit design, including constraints from the existing plant and the permanent seek for cost and schedule optimization has reached its first step. The implementation of the equipment after more than 3 years of huge civil works will be the next step of this project.

A close cooperation between the Owner and its Engineer since the very early stage of design as well as a strong implication of the manufacturers have made this project possible, and will ensure the delivery of a first class hydromechanical equipment.

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