Abstract

The Fully hydropower scheme was commissioned in 1915 and taps one of the highest heads worldwide (approx. 1640 m). In 2010 a through assessment of the penstock showed evidence of corrosion that cannot guarantee its aptitude for service until the end of the present concession term in 2085. The paper presents the main conclusions of the rehabilitation studies as well as of the project currently being implemented. The retained rehabilitation concept consists of reducing the internal pressure on the penstock and on changing the operational pattern of the power scheme (with reduction of the design discharge) for equal annual energy production. The technical-economical feasibility of the rehabilitation project considers the existing incentives to the production of renewable endogenous energy established by the Confederation. The project takes place at work sites between 500 and 2100 m of altitude. The tender process for equipment supply was recently completed and beginning of construction works is foreseen in April 2015.

Keywords: Small-hydropower plant, renewed concession, steel penstock, water-supply system, high-head.

1. Introduction

The Fully hydropower scheme was commissioned in 1915 and hold until the 1930’s the record of the highest head worldwide (approx. 1640 m). The scheme is situated in the Canton of Valais in Switzerland, between Martigny and Sion, on the right bank of the Rhône River valley (Figure 1). Until 2005 the Forces Motrices de Fully (FDMF) were own by Energie Ouest Suisse (EOS), the largest energy utility in the French-speaking part of Switzerland. A new concession was awarded in 2005 until 2085, being the FMDF now controlled by the local municipality which holds a 72% share of the company, while ALPIQ Suisse (including EOS) holds the remainder share.

2. Existing Power Scheme

2.1. Original scheme

The power scheme uses the natural inflows to two mountain lakes, located at high altitude above the town of Fully. The upper lake is the largest and its storage capacity was increased by the construction of a 14 m high masonry dam at the natural outlet (Figure 2). The lower lake is the Sorniot Lake, whose inflows have been so far pumped to the upper lake (Figure 3). The lower lake catchment accounts for one third to half of the total inflows to the system.
The water is conveyed from the upper lake directly to the powerhouse located in the Rhône River plain, approximately 1600 m below, in one single stage, via a steel penstock of either 500 or 600 mm diameter. Pumping between the two lakes is done using the same penstock. The steel penstock is 4673 m long, of which roughly 1 km in three tunnel stretches and the remainder length is buried in trenches. The steel pipe thickness is 6 to 8 mm between the two lakes, increases regularly to 20 mm from Sorniot to Garettes (at 1500 m above the sea level [asl]) and is maximum of 41 mm at the entry of the powerhouse (Chenaud & Du Bois, 1922).

The powerhouse (Figure 4) was built to house 4 units, each a 2.2 MW horizontal Francis group. The scheme was operated until 2013 for peak power production, filling up the main reservoir during snowmelt in spring time (and eventually using the excess water for production) and then waiting until winter time to generate energy mainly at peak time. Keeping the reservoir full during most of summer and autumn often led to spillage and dam overtopping. The average annual inflows to the system are 3.6 hm$^3$ with significant variation (approx. btw 2.5 to 5.3 hm$^3$ over the last 20 years), leading to an average electricity production of 10 GWh/year.
2.2. Main events during the first concession period (1915-2005)

In 1961 a second entry to the intake tower was done underwater, which increased the useful volume.

The Fully dam reservoir could thus be managed at lower levels and spilling was significantly reduced. In 1967 the four turbine units were replaced by a single 6 MW unit with a rated discharge of 480 L/s, placed at the basement of the powerhouse. A new 460 hp pump was installed at Sorniot.

In 2000 a major accident occurred between Sorniot and Garettes with rupture of the penstock. A major landslide occurred immediately at the Sorniot tunnel outlet taking 900 m of DN600 penstock pipes with it.

No casualties were registered downstream and the scheme was out of service. Works were carried out from 2004 to 2006 to build a new stretch of tunnel circumventing the landslide zone and new DN500 penstock pipes were installed. The power scheme lost the production of 5 snowmelt seasons. During that period a watertight membrane was installed on the upstream face of the dam and several hydro-mechanical elements were replaced at the intake and intermediate valve chamber.

2.3. Assessment of penstock status

After renewal of the concession and re-commissioning of the scheme, frequent repair of penstock leakage and evidence of corrosion on the broken penstock pipes aroused renewed interest on the structural status of the penstock. Doubts over the penstock’s aptitude for long-term service justified carrying out extensive measurements of penstock thickness and assessment of its structural safety factor. Corrosion rates were deduced per stretch and a thorough assessment of the safety factor at future time milestones showed that important reduction in safety is to be expected at several reaches, before the term of the present concession in 2085.

2. The interest of the new reference shareholder, the Municipality, to use the mountain water resources to satisfy the population’s needs all year round, as an alternative to pumping wells located in the Rhône River valley, thus combining electricity production with water supply.

To satisfy the first objective several technical options were considered, from local replacement of old pipes per new pipes as per the needs, or tubing (placing new thinner pipe inside old one) or reduction of internal pressure by creation of intermediate stages. Coping with the second objective revealed however that a major change in operation practice is required.

3.2. Framework incentives to small-hydro production

Following the accident at Fukushima nuclear plant in Japan in 2012 the Swiss Confederation established a new strategy up to 2050 aiming, among other things, at reducing the dependency on nuclear energy and increasing the share of electricity of renewable endogenous sources.

The existing framework set by the Energy Directive (OEnE) since 1998 has been object of several updates, the applicable law for small hydro project entering in force in 2012 (it shall be updated from 1st January 2014). The existing framework allows hydropower owners and/or developers to apply for a fixed-remuneration program, in which all energy produced is bought by the grid at a fixed rate during 25 years (to be reduced to 15 years after 01.01.2014 in most cases with increased rates).

The fixed rate is estimated via a procedure taking into account the cost of the facilities (without the electromechanical equipment) and the electricity produced. It is labelled “remuneration at cost price” and can be seen as a feed-in tariff. The program for grid connection of small hydro plants is presented in the Appendix 1.1 of the revised OEnE.

Of particular interest for FMDF is the fact the use and upgrade of existing schemes is clearly seen as contributing positively to reaching the 2050 goals. Also, the feed-in tariff may comprise a bonus for rehabilitation works carried out over the past 30 years (as function of their residual value according a linear decay rate).

This is an extra incentive for generalized good maintenance of hydropower facilities in Switzerland and part of the works carried out by the FMDF in 2004/06 are likely eligible.

3.3. Connection with the water supply system

Water demand is fairly low throughout most of the year, in average 55 L/s (or approx. 4600 m³/day) reaching 150 L/s during summertime due to irrigation.

This scenario is more adapted to a progressive slow depletion of the main reservoir after snowmelt and in Autumn, in direct conflict with the previous operation pattern of FMDF. In the absence of an intermediate urban reservoir (min. 5’000 m³) between the hydropower scheme and the water supply system, the operation of the former became somewhat dependent of the constraints of the later.
Only during snowmelt the FMDF can operate free of downstream constraints, when inflows largely exceed the water supply demand and can fill up the upper reservoir in roughly 2 months.

3.4. Alternatives for hydro rehabilitation

Renewing the penstock for identical head corresponds to a large investment, occurring after 5 years of outage (2001-2006). Therefore, the favored rehabilitation strategy to reuse the existing penstock was to reduce the internal pressure by creation of intermediate stages.

The main questions were therefore where to place the new stages, how many stages should be considered and what should be done to the pumping station at Sorniot. No alternatives implying long penstocks were considered.

Two main groups of alternative layouts were investigated, with and without pumping. Without pumping meaning that the inflows to the lower lake would have to be conveyed down independently (in time) from those from the upper reservoir, using the same penstock. Or, that an intermediate stage would be created at Sorniot, reducing the internal head to the entire penstock downstream by approx. 130 m.

In any case, without pumping means that no possibility to store up at the dam excess water during flood events considered at Sorniot would be kept. Should no additional intermediate stage be provided further downstream, the maximum pressure acting at the lower reaches of the penstock would still be of 1500 mWC. Therefore, in both groups of alternative layout, intermediate stages at either Garettes or Planuit were investigated, reducing the maximum internal pressure of additional 400 to 600 mWC downstream. The identified alternatives were compared in terms of their present value and return on investment, estimated considering the electricity revenues and the construction and equipment supply costs.

3.5. Energy studies and selected rated discharges

The energy output and the rated discharge for each stage was defined using a simulation model of the complete cascade.

First the existing scheme and its operation pattern were reproduced. In the absence of direct measurements of the inflows to the two lakes and of the used discharge, the model was built using as initial data the lake levels, the generated energy at La Belle Usine and the consumed energy for pumping at Sorniot. Assumptions were made regarding water extraction for other users.

The outcome was an estimation of the spillage, per typical hydrological years (dry, average, wet). Second, the new cascade layouts were tested, one by one, considering the same hydrological conditions. The rated discharge for each stage was investigated such as to guarantee the downstream water demand and minimize spillage. The most important conclusions of this study were:

- For identical hydrological conditions, the new cascade produces identical electricity output (in average 10 GWh/year with total 3.3 MW of installed capacity) although in a different annual pattern;
- The rated discharge between the lower lake and the Rhône River plain is around 250 L/s, considerably lower than the present rated discharge, reducing flow velocities, friction losses and transient pressures on the penstock, as well as the cost of the groups and valves;
- The rated discharge between the two lakes can be between 150 and 250 L/s, operation not being necessarily coupled with the downstream stages;
- Spillage is significantly reduced;
- The annual water level variation range of the upper lake is of approx. 20 m, most of which within the natural lake elevation, thus using only the first 3-5 m of the 14 m high dam.

3.6. Selected layout alternative

The economical analysis led to the selection of a layout without pumping. In fact, instead of storing all water at the dam for winter electricity generation, the inflows to the lower lake are directly used in a run-of-the-river pattern. The selected layout comprises three stages (see Figure 5), the first being created in between the two lakes, with approximately 136 m of gross head. An intermediate stage is located at Garettes (El. 1550 m asl), which is the uppermost location one can access by forest road and exactly the downstream end of the most recent reach of penstock set in 2005/06. The internal pressure on the lower stage penstock, between Garettes and La Belle Usine (Verdan), is thus reduced of almost 600 m of head, being limited to 1050 m of downstream.

The lower lake with a live storage of 30’000 m³ is used as headpond for the two lower stages. At Garettes a 30 m³ forebay is used to make a transition between the second and third stages. The final connection with the water supply system is done at the Verdan tailrace, where the municipality will install a pumping station to their water filtration plant.

3.7. New operational patterns and challenges

The new cascade operation mode is characterized by two distinct patterns:

- During snowmelt, most of the generation is done using the direct inflows to the lower lake, storing all inflows to the upper lake. Only when inflows to the lower lake recede will the water from the upper lake be used as a complement. In this pattern, operation is governed by the level of the lower lake, to reduce spillage as much as possible. The water used for power generation at Verdan in excess of the municipality needs for water supply is lost downstream.
- Outside snowmelt period, electricity production will be done only when water is conveyed to the water supply system, as per the demand diagram. Daily modulation (to adapt production to best remuneration hours) might be possible depending of the downstream pumping and storage capacity of the municipality. The main reservoir will be progressively depleted and little to no water shall leave the system.

The above operation pattern is quite unusual for hydro plants, used to depend on hydrology and look for the best remuneration hours for electricity generation.
That is the case only during snowmelt, when the cascade is regulated based on the upstream water levels. Throughout the remainder of the year the cascade is governed from downstream, as function of the water level in the Verdan tailrace. The command-control system of the cascade must therefore guarantee the proper functioning of the cascade in these two normal operation patterns, as well as for the abnormal operation scenarios. Despite the small-hydro characteristics of the project, the complexity of the cascade present unusual challenges. The design of the forebays as well as of the turbine regulators must guarantee proper reaction of the system, without unacceptable spillage, transient pressure or air entrainment. The measuring devices must feed properly the command and control system with reliable, accurate and redundant data.

4. Rehabilitation Project

4.1. Introduction

Following the selection of the layout the project entered a second phase where the detailed functions of each scheme were defined and a specific design adapted to each location was developed.

The project presents quite varied features with work at 2100, 1980, 1540 and 490 m of altitude, with different constraints regarding the physical environment, briefly presented below.

The selection of the hydro and electro-mechanical equipment aimed at guaranteeing good enough efficiency for a large range of discharges throughout the year, guarantee the continual supply of water to the municipality (in case of turbine or transmission line failure and so on) and limit noise.

However, some challenges were rather unusual, as selecting Pelton turbines for over 1050 m of head, or pressure-release valves for 400 and 1050 m of head without having large reservoirs for residual energy dissipation. To make matters worse an accident with the group in January 2013 lead to turbine outage. Failure of a few runner buckets lead to the collapse of the turbine cast iron casing and major damage to the entire turbine room, fortunately without human injury. The FMDF then decided not to rehabilitate the group and to discard the option of reinstalling a new group inside the Belle Usine, which in recent years has become one important location for performing arts rehearsal and public shows.
4.2. Water supply constraints

Water treatment for the different consumers supplied by the Municipality is done downstream of the hydro cascade. To reduce the needs for treatment, all new powerhouse piping and fittings in contact with water are stainless steel, including the nozzles and turbine runners. Turbine lubrication is biodegradable.

4.3. Sorniot SHP

Sorniot powerhouse results from the conversion of the pumping station at El. 1990 (Figures 6 and 7) and reuses the existing 10 kV aerial transmission line.

Figure 6. Sorniot powerhouse: plan view at machine hall level. New turbine on top left corner. Water flows from left to right.

Figure 7. Sorniot powerhouse: vertical cross section through turbine axis and upstream manifold axis. New turbine on the left side (old pump is shown in light grey behind). DN600 penstock arrival on the right side. Water flows from right to left.

The existing pump and ancillary devices are dismantled, as well as the oil transformers and electrical cubicles. The existing 4-ton overhead crane is kept. A 3-jet 200 kW vertical Pelton unit is installed at the old location of the pump. The connection with the upstream penstock includes a turbine by-pass system equipped with a pressure reduction valve. At the basement of the powerhouse two basins are available and communicate with the lake: one is used to collect the water passing through the turbine, another feeds the intake for the second stage between Sorniot and Garettes. The intake for the next stage is equipped with a safety valve closing by counterweight action upon overspeed detection. At the machine hall level a new partition is done to house a new resin transformer and medium-voltage cells.

4.4. Garettes SHP

The powerhouse is located on a narrow platform at El. 1550 at a location where the original cableway for construction and access to Sorniot had its lower station. The cableway is no longer used.

The mountain road ends at this location, where the site installations were located during the 2004/06 rehabilitation works carried out on the penstock. The powerhouse is located approximately 40 m eastwards from the penstock in order to move away from the avalanche risk zone and come closer to the existing 16kV aerial transmission line. However it is located in a zone of various geological risks, which justified carrying out detailed rock fall trajectory studies.

A dynamic protection barrier is foreseen on the mountain side of the powerhouse. The location is also a protection zone for groundwater recharge, which obliged to reduce excavation depth and develop a specific concept for foundation drainage preventing groundwater contamination.

Garettes powerhouse is entirely new (Figures 8 and 9) and houses a 2-jet 900 kW vertical Pelton group, a turbine by-pass system equipped with a pressure reduction device, a 30 m³ water reservoir, the transformer room, electrical cubicles and the intake for the lower (third) stage. The powerhouse is linked to the existing DN500/600 penstock via new DN300 extensions in cast iron.

Figure 8. Garettes powerhouse: vertical cross section through turbine axis.

The powerhouse’s footprint was sized mainly according to the group’s main dimensions.
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The reservoir’s height was imposed by the water volume required to guarantee a proper hydraulic regulation between the 2nd and 3rd stages of the cascade and intake submergence, whereas the machine hall height was mainly conditioned by the height of the generator and of the transformer. Equipment maneuvering on site is done using a mobile crane and equipment access during erection and/or maintenance is done by means of one removable hatch cover on the top slab. Manholes and grating plates provide access to the reservoir and valve cubicles. An overflow weir followed by a 110 m long conduit release spillage water directly on a neighbouring torrent. Access for the transformer and people is done on the least exposed side to avalanches, as well as all ventilation openings.

Figure 9. Garettes powerhouse: plan view at machine hall level.

4.5. SHP Verdan

The Verdan powerhouse is located immediately upstream from the Belle Usine. Two alternative solutions are still being considered to equip the powerhouse with either 1 or 2 units, as proposed by the equipment suppliers (tender process ongoing). The retained architectural concept favors the explicit contrast between the ancient and new buildings being used for hydropower generation (Figures 10).

Figure 10. Verdan powerhouse: view from East showing the new powerhouse (right) and the Belle Usine (left). Source: Bureau Nunatak.

The powerhouse comprises a machine hall level, a 80 m³ water reservoir below and under the same footprint, and an appended underground pumping station diverting water to the Municipality water supply system (Figures 11 and 12). The group transformer is placed on the road side next and partly above the penstock anchor block. The equipment is maneuvered during erection and maintenance with the help of a mobile crane and equipment access to the powerhouse is done by means of two removable hatch covers on the top slab.

Figure 11. Verdan powerhouse: plan view at entry level (solution with 2 units).

Figure 12. Verdan powerhouse: vertical cross section through the access ramp to the machine hall (solution with 2 units).

5. Outlook

The project is currently under evaluation by the authorities. Public auditioning and construction permit awarding are expected to be completed within 2014. Turbine ordering and the civil works tender are expected early 2015. Turbine manufacturing shall be initiated in 2015. Construction works are expected to start at Verdan at the end of 2015, move up in altitude as snow melts. Commissioning is scheduled for October 2016.

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