Swiss Section

A big rechargeable battery in the Swiss Alps

George Raymond

Most of us charge our mobile phones' batteries at night so we can use them during the day. Given that energy supply and demand vary over time, the railway system – and society as a whole – also need energy storage. As the share of energy coming from renewable sources like sun and wind increases, so does the volatility of supply. Consumption also varies over the day, week and year. While the consumption of Switzerland's electrified trains is largely predictable, other functions such as heating and cooling buildings depend on factors like the weather.

On 24 August 2018, 14 members and five guests of the IRSE Swiss Section rode 88 km southeast of Zurich for a look inside a very big rechargeable battery: the Limmern pumped-storage power plant (LPSP). Our hosts at the LPSP were Willy Schönenberger and Kurt Steiner. IRSE member Marco Lüthi organised the event.

When demand and electricity prices are high, the LPSP sends water from Lake Mutt, high in the Alps, through turbines linked to generators to make electricity. Conversely, when demand and prices are low, it buys electricity and feeds it to these same machines to power the turbines and pump water back from Lake Limmern to Lake Mutt, 630 metres higher up. It is the largest and highest such system in Europe.

80-year business model

LPSP is part of Kraftwerke Linth-Limmern AG (KLL), of which Axpo owns 85% and the Swiss canton of Glarus 15%. The LPSP's business model is simple: over the 80-year life of its concession, the difference between what it pays and earns for power must well exceed the plant's 2.1 billion-Swiss-franc construction cost and its operating costs. The LPSP also plays an important role in both ensuring a reliable electricity supply and keeping electricity grids stable.

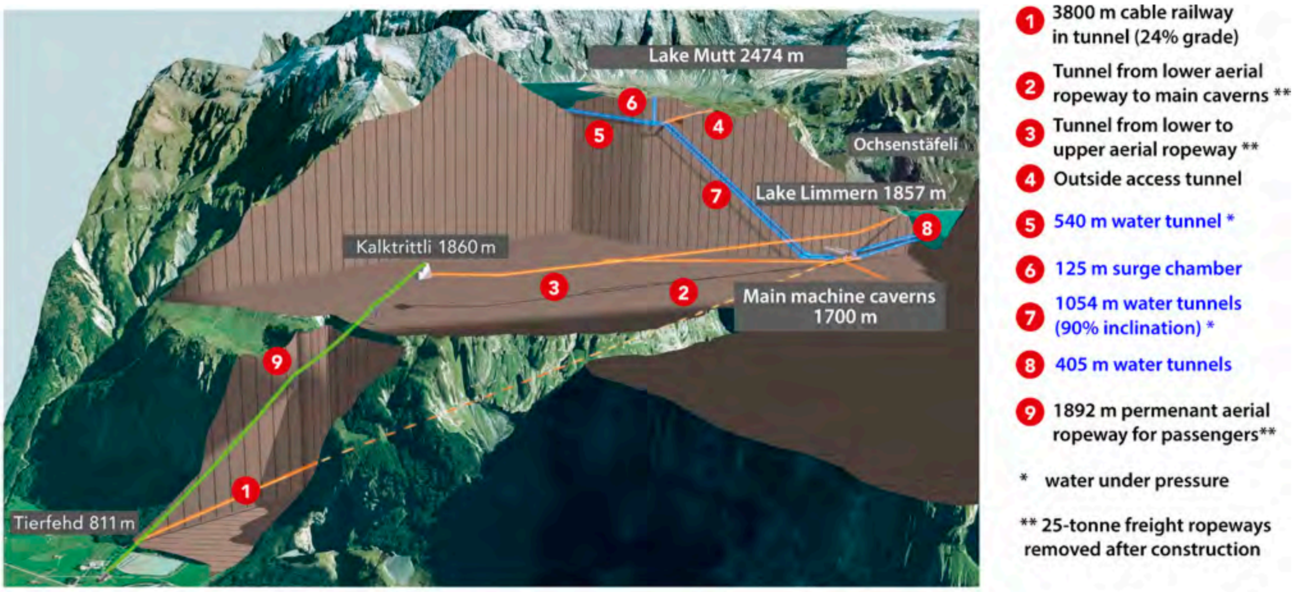
Five bodies of water

The LPSP is part of the KLL power plant and its five bodies of water shown in Table 1.

Today's KLL opened in three phases:

- 1963-1968: A 146 m tall, 370 m wide dam built on Limmern Creek in 1957-1963 created Lake Limmern. From 1968, Lake Limmern and the Hintersand and Tierfehd basins fed water to generators whose approximate total rating was 335 MW then and is 386 MW now.
- 2009: The Tierfehd pumped storage plant started operation. It added a 138 MW turbine that can also act as a 131 MW pump between Lake Limmern and Tierfehd basin.
- 2016-2017: The new LPSP started operation. Its four turbines have a combined rating of 1000 MW – comparable to that of a Swiss nuclear plant – and can also function as pumps. The plant can either pump water from Lake Limmern up into Lake Mutt or release water from Lake Mutt to generate power. Building the LPSP raised the KLL's total rated plant capacity from 524 to 1524 MW.

The underground Limmern pumped-storage power plant (LPSP).
Source: Axpo, adapted by the author.



Body of water	Altitude (metres)	Millions of cubic metres	Pump power (MW)	Generator power (MW)
Lake Mutt	2474	23		
			1000 ↑	1000 ↓
Lake Limmern	1857	92		
			34 ↑	444 ↓
Hintersand basin	1298	0.11		
			131 ↑	46 ↓
Tierfehd basin	812	0.46		
				34 ↓
Linthal basin	676	0.22		
				↓
River Linth				

Table 1 – the five bodies of water comprising the KLL power plant.

A tight schedule in a remote, delicate setting

In 2007, the designers of the LPSP faced numerous challenges, including an ambitious time schedule; construction logistics at roadless, high-altitude sites; concerns for the delicate Alpine environment; and the plant's required high reliability and availability.

The design and placement of the network of caverns and water and service tunnels took account of geological conditions, the building and operation phases and possible emergencies such as cavern flooding or fire from an overheated generator.

The LPSP project enlarged Lake Mutt Dam to a height of 35 m and width of 1054 m and raised its water level 28 m to an altitude of 2474 m so it could hold 2.5 times more water. Construction required two temporary, 25-tonne aerial ropeways to transport cement trucks and other large equipment. These ropeways ran from Tierfehd to Kalktrittli and from Ochsenstäfeli (altitude 1,880 m) to Lake Mutt (see diagram). Equipment such as two 180-tonne cranes and a 700-tonne tunnel boring machine moved in pieces. Up to 500 people worked in various places on the site at once. Winter snowfalls of up to 4 m restricted work on the Lake Mutt Dam to summer.

A 3.8 km tunnel railway at 24% grade

Since 2013, heavy equipment such as turbines, generators and transformers have been reaching the main caverns on a 3.8 km, cable-powered tunnel railway on a 24% grade.

Switzerland is known for its narrow-gauge rail networks, but the gauge of KLL's railway is a broad 1.8 m to keep large turbine parts and transformers from tipping.

The IRSE group's conveyance on the 3.8 km ride to the main caverns. *Photo Sascha Schneider.*

Two motors rated at 870 kW each power the inclined railway's cable. *Photo Peter Hefti.*

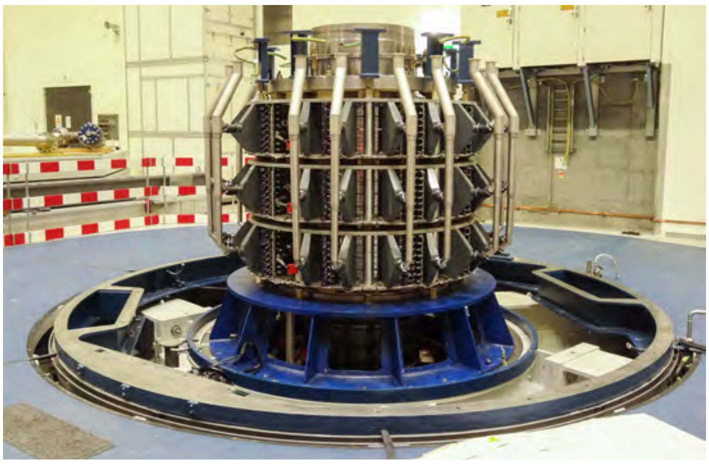
A film showed that the inclined railway brought some large components in pieces. The 40-tonne wagons run at 6 m per second empty, but at only 0.5 m per second when carrying their maximum load of 215 tonnes. *Photo Markus Grämiger.*

In the main cavern: four pump-turbines

A cavern 150 m long, 31 m wide and 54 m high – including multiple floors – houses the LPSP's four pump-turbine sets. Each set is rated at 250 MW and makes about 500 revolutions per minute to handle 47 cubic metres of water per second when generating and 40 when pumping.

Housings and parts of disassembled motor/generators in the main cavern. When operating, the 16-metre-high machines are below the floor.

A pump/turbine is located below us and its motor/generator above us. The vertical shaft connects them. A so-called guide vane directs water into the moving blades of the turbine for minimum loss of energy.



Disassembled top of a motor/generator set showing the slip rings that transmit the rotor's excitation current. This current creates magnetic fields in the rotor to control the speed and torque of the vertical shaft connecting the turbine and the motor/generator for optimal performance. The exterior pipes vacuum carbon particles away from the slip rings. *Photo Markus Grämiger.*

Conduits that carry the rotor's excitation power, which is about one-tenth the power the whole motor/generator handles. Sascha Schneider, who took this photo, later patiently explained to the author a number of important details, including how excitation currents regulate the speed of motor/generators.

An adjacent cavern houses switching stations and four transformers rated at 280 MVA each. Rock excavated from the caverns went into concrete for both interior works and Lake Mutt Dam.

Comments by IRSE participants

Marco Luethi was impressed that the entire plant was planned and built within 10 years. Patrick Sonderegger called the seven-year construction phase very short. Work proceeded in many places at once. True pioneers were at work. Markus Gräminger called the huge facility an important basis for the stabilisation of the Swiss electric power network.

One key to the LPSP's profitably is fast changeovers between pumping and generation ("charging" and "discharging") modes in response to price swings on the electricity market. Patrick noted that the plant can make a changeover in 3 to 6 minutes, and does so up to six times a day.

Above left, one of the 180-tonne valves, built for a pressure of 105 bars, whose movable sphere can restrict flow to 30% in 6 seconds and shut completely 36 seconds later.

Above right, a sphere valve in place and ready for action. Each sphere valve has two motors, an emergency generator and a mechanism that can close the valve even if the motors and power fail.

Oskar Stalder observed that logistics dominated the project (given for example the tunnel profile and the load limit of the aerial ropeways); that impressive know-how lies within the huge machines and complex control system; that huge physical forces (water volumes and speeds) are mastered; and that the dimensions and output of the whole plant are impressive.

"And I had always thought that railway signalling systems were complex", said Daniel Pixley.

Sources: KLL, Axpo, Wikipedia and "The Linth-Limmern hydro-power plant – Design and construction of a large pumped storage scheme", Müller et al, World Tunnel Congress, Geneva, 2013.

Photos by the author except as noted.