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Pumped storage hydropower plants in Austria

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Abstract

The aim of this work is to get a brief and visually appealing insight into the individuality and complexity of pumped storage hydropower plants in Austria. Considerable investments for the expansion of pumped storage hydropower plants in the Alpine region were made in recent years.

The idea of hydraulic power storage through pumping started already at the turn of the century. Already in those days, the development of a pumped storage hydropower plant needed many years. Each hydropower plant differs individually and more or less unique. The plants differ depending on the location, position, regional conditions, hydraulic and structural conditions, type of machines and so on. From the start of the design until the commissioning, also the requirements for mechanical engineers, geologists or metrologist are very time-consuming and challenging.

The significant advantage of pumped storage hydropower plants is their flexibility. The daily and weekly curve of electricity consumption have high fluctuations and have impact on the price of energy. The plants can react responsively and flexibly on the fluctuations in production and consumption. This means to select the correct operating mode (pumping or turbineing) at the right time. The pumped storage hydropower plants store electricity by e.g. wind power with an unbeatable high factor of efficiency. The hydropower plant is able to pump the water up and if there is more need of electricity, the plant discharges the water back to the lower reservoir, so energy is invested and returned.

Special focus is set to the graphically adaptation processes of the hydropower schemes. A uniform representation of the pumped storage hydropower plants was another top priority on this work. This work covers the design and construction of the hydropower plant components such as the reservoirs, the intakes, the power water ways (headrace and tailrace tunnels), the surge tanks, the power house including the machine units and their technical and unique refinements.

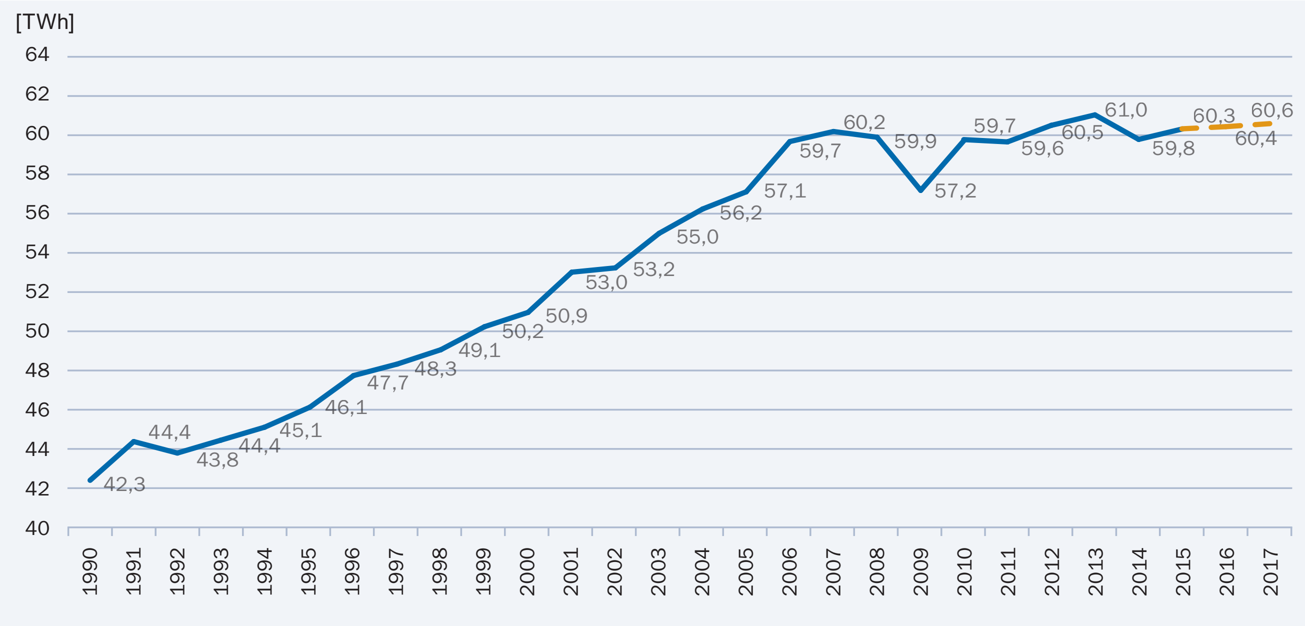
Contents

I. INTRODUCTION

The use of hydropower in Austria dates back on a long tradition and a historically grown renewable energy source. Hydropower contributes significantly to the Austrian energy generation. A balanced mix of energy sources is the basic of energy consumption in Austria. [3]

Since 1990, the energy consumption in Austria increased by approximately 43%. Which is largely a consequence of technical progress, changing lifestyle and economic growth. The national electricity consumption is growing by an average between 1% and 2.5% per year. [3]

The following figure shows the electricity consumption of the past few years starting at 1990 and a makes a prognosis for 2017.



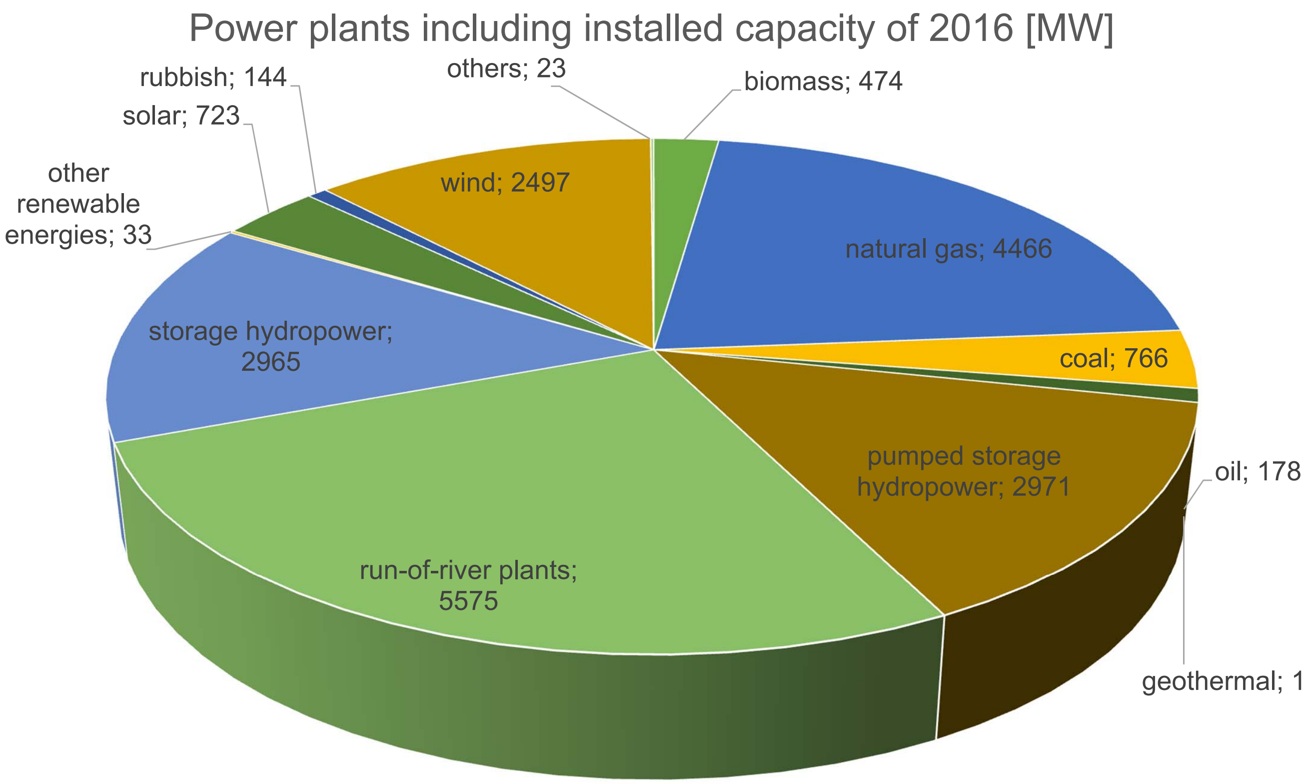
Electricity consumption [TWh] in Austria from 1990 until 2017 [12]

Currently, around 2880 hydropower plants produce 65.7% (47.6 TWh per year, 171.3 PJ) of the national gross electricity generation. Including those hydropower plants which generate electricity only for their own consumption, in total over 5200 hydropower plants are operating in Austria. [3]

Around one third of them are storage or pumped-storage plants and the remaining of the hydropower plants are run-of-river plants. Today, the hydropower development is more often focused on extensions, modernizations and efficiency extensions of existing plants. [3]

In the group of pumped storage and storage hydropower plants around 20% have a daily, 12% a weekly and 68% an annual storage reservoir. Pumped hydropower plants can storage the not immediately used surplus production of e.g. large-scale wind farms. If there is a surplus production, but no need of electricity the plant can provide grid stabilization. [3]

Austria has 14 % of the European pump storage capacity and is called “the green battery of Europe”. Hydropower plants produce electricity without emission of CO_2 or NO_x, due to Austria avoid around 15.3 million tons emission of CO_2 per year. [3] In comparison, energy sources such as coal have 882 g/kWh CO_2 emission or oil and its products have 645 g/kWh CO_2. [13]

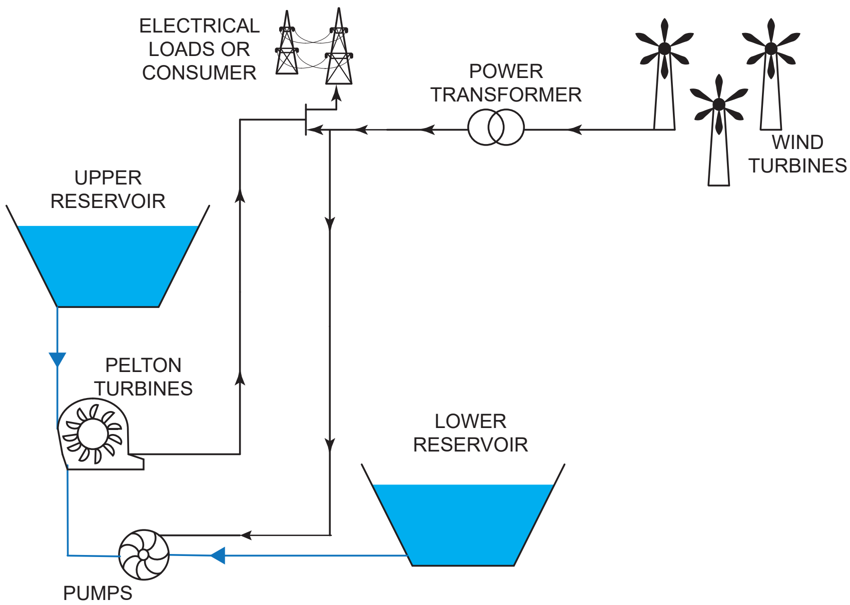


Power plants including installed capacity of 2016 [MW] [10]

A. PUMPED STORAGE HYDROPOWER PLANTS

Pumped storage hydropower plants belong to high-pressure plants and especially accumulate energy until electricity is required. The plant consists of an upper reservoir, a lower reservoir and in between a headrace system and a powerhouse or a machine cavern. [4]

The energy in the movement of the water is transformed into electricity at the powerhouse or machine cavern. The powerhouse or machine cavern consist of mechanical components, electrical equipment as well as control engineering and control technology. [4]



Conceptual wind power based pumped storage system [3]

The upper reservoir is umpteen meters higher than the lower reservoir. Pumped storage hydropower plants use the hydro energetic potential through pumping to produce the electrical energy. PSH´s (pumped storage hydropower plants) essentially not generate additional energy, apart from the supplementary use of the natural run-off flow of water. Basically, the used energy to pump is higher than the energy which is recovered by the downward flow. [3]

The so called hybrid power stations, a combination of wind and pumped-storage system, represent a realistic possibility. This allows to realize a high renewable penetrations. The pumped storage hydropower plants essentially provide energy for peak load shaving. It is the most commercially way of large-scale grid energy storage. Losses result from charge/discharge processes (friction losses), efficiency of the pump or turbine, efficiency of the motor or generator, transformer losses as well as own consumption of the plant to a lesser extent. [3]

The possibility of satisfying the needs of a pumped storage hydropower plant is primarily affected by the given chances of realizing. Existing infrastructure such as existing storages, chains of reservoirs and efficient networks influence the possibility.

For this reason, modern pumped storage hydropower plants mainly use existing storages, headrace systems etc. such the pumped storage hydropower plant Koralpe. [7]

The overall efficiency of a pumped storage hydropower plant is between 70 and 80 %, exceptionally little higher than that. In general, it is lower than that of high-pressure plants, because of the additional efficiency of the pump. Added to this are further losses of the initial transport and the return of electrical energy (transmission losses). [4]

Transmission losses depend on the geographical distance between energy generators, pumped storage hydropower plant and consumer of energy. In case of cheap electricity is available to pump, pumped storage hydropower plants are economical. [4]

In accordance with the rated power, hydropower plants can be classified into large (>10 MW), small (<10 MW), micro (>100 kW) and pico (<5 kW) plants. The installed capacity can change from a few hundred kW up to several MW. Although there is no official definition of the hydropower plant size. Generally, pumped storage hydropower plants tend to belong more to the large and small plants. [3]

A lot of pumped storage hydropower plant were built after the Second World War. In the night, the industry needed less energy than produced through thermal power plants. During the years, pumped storage hydropower plans became less important. Today they are mainly used as capacity frequency control in the interconnected European electricity system. [3]

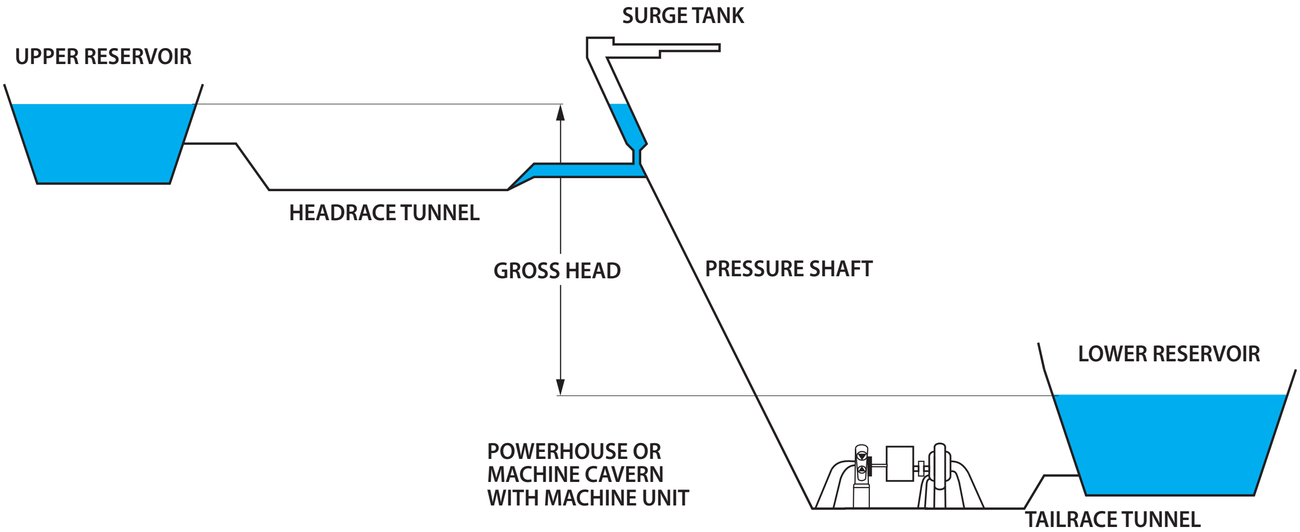
This is becoming increasingly important because the rapid growth of the renewable energy production such as solar power, wind power and partially biomass energy. The mentioned plants irregularly produce energy. Pumped storage hydropower plants compensate the change between high (e.g. stronger wind) and lower (e.g. weak wind) electricity production. [3]

Previously, the plant pumped times at night for hours and the turbine produced energy during the day. However, today the change between pump operation and turbine operation is more frequent. Today they especially cover the daily peaks of electricity requirement. [3]

B. PLANT COMPONENTS AND MODE OF OPERATION

A pumped storage hydropower plant generally consists of following components:

- Upper and lower reservoir with some retention structure including a spillway, a bottom outlet, intake/ outlet structure
- Headrace system comprising headrace tunnel, pressure shaft and surge tank
- Powerhouse or machine cavern including the machine units
- Auxiliary structures such as energy supply tunnel, valve chambers etc. [5]

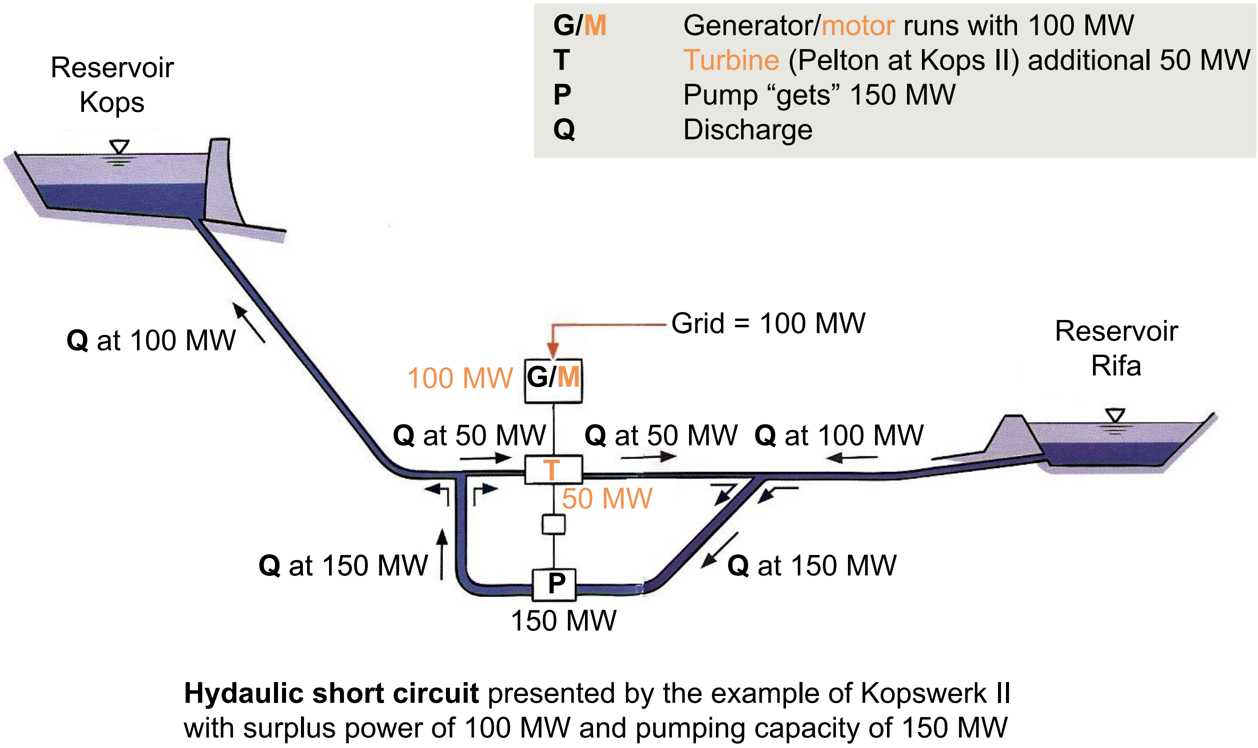


Hydropower scheme of a pumped storage plant

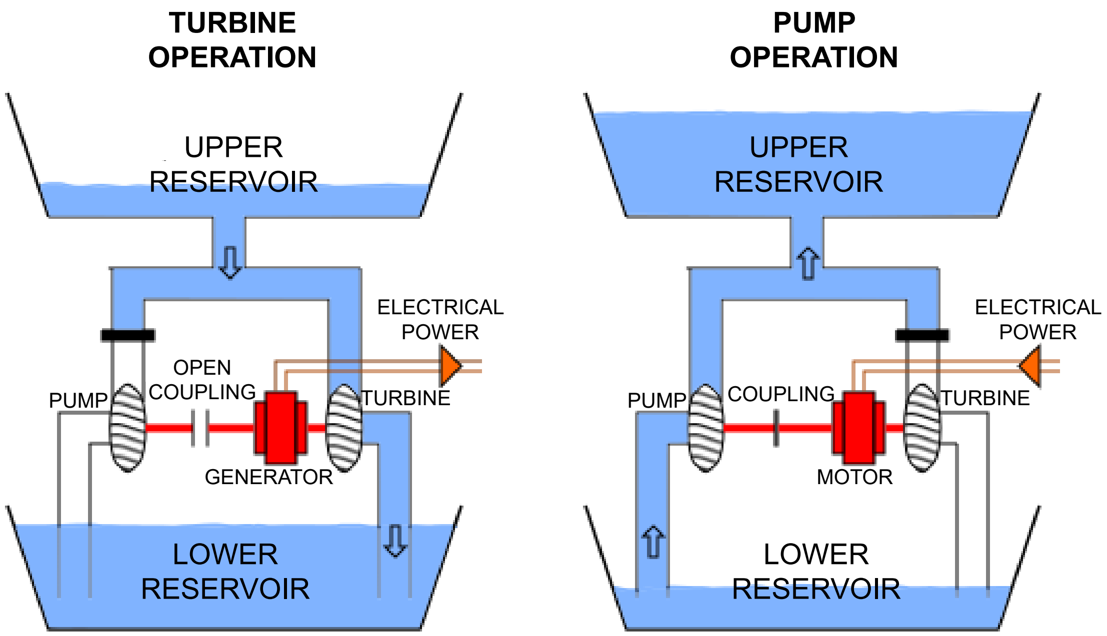
A turbine, a pump and an electrical rotating machine is situated at the machine hall, in the simplest case. The electrical rotating machine could rather be an electrical generator or electric engine. One or more such machine units are parallel installed for larger plants. The turbine, the generator, the pump and some auxiliary equipment (e.g. coupling) are mounted on a common shaft. The generator has usually a three-phase synchronous motor with an excitation device. Three-phase asynchronous machines have no start-up problems, which some power plants have installed as an alternative drive motor. Consequently the generator only operate as synchronous machine.

Electrical machines can work as generator operation as well as motor operation. Contrary to turbines, which cannot work as a pump. For this reason the turbine and the pump are separated. The turbine could be a Francis turbine, as separate unit and connected to the headrace tunnel with gate valves depending on the operation mode. The turbine run without function during the pumping operation, which means the turbine is idle running. Conversely, the pump has to be shut-down during generator operation, since this can lead the whole installation to malfunction. Therefore the coupling disconnect the pump and the shaft in generator operation.

A pump turbine as an alternative to the ternary machine unit can be installed at the pumped storage hydropower plant. A pump turbine is a turbomachine, which can operate in both directions. One machine can change from pump to turbine operation and revers. The use of the regulating pump is a special operating mode and also known as hydraulic short circuit. The minimum of a subset of water is fed back through the turbine. This operation mode is just possible through the separation of the pump and the turbine runner. E.g. the Kopswerk II in Vorarlberg uses the hydraulic short circuit. In regard to the temporal cycle, pumped storage hydropower plants can distinguished in daily storage plants, weekly storage plants and annual storage plants. [5]



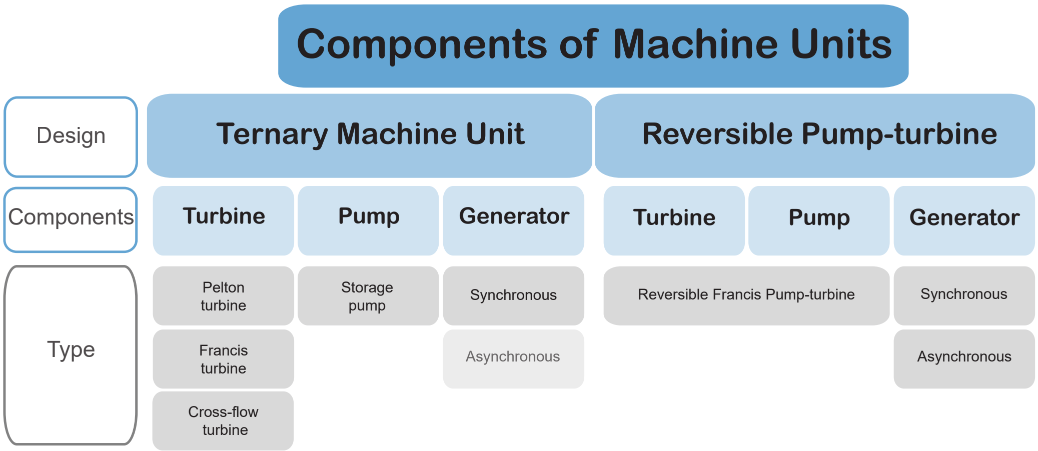
Hydraulic short circuit presented by the example of Kopswerk II [13]



Turbine and pumping operation [15]

C. MACHINE UNITS OF PSH

The machine units have requirements such as local, topographical, hydrological and structural conditions as well as energy-economical and operational requirements. The machine units are exposed to considerable loads due to frequent operation changes and have to withstand these.



Components of machine units [6]

Frequent operation changes means a quick switch from standstill to full-load operation. Also a reaction to load changes with frequency fluctuations has to take into account. Generally, the main hall is below the geodetic suction head of the lower reservoir to avoid cavitation. The installed machine units affect the controllability and the application of the pumped storage hydropower plant. The immediate reaction of the pumped storage hydropower plant influence the adaption on the variations of the utility and, therefore, participation in the regulating power markets. In the earlier stages of pumped storage they used different units with separated turbine/generator and pump/motor, which used the same penstock. The capacity of them was 1 MW. At a later stage, the ternary machine unit was developed, this means that the turbine, pump and generator are together attached on a shaft. This configuration is called ternary arrangement or ternary machine unit. In the middle of the 20th century, the single-flow reversible pump-turbine has made a significant breakthrough. The possibility of multi stage reversible pump-turbines enables higher gross heads.

machine type:	ternary machine unit	pump turbine
investments	-	+
machine dimensions	-	+
efficiency	+	-
depth of construction	+	-
switching time: P->T/T->P	+	-
hydraulic short circuit	+	+ (with 2 Francis machine units)
operation costs	-	+
maintenance effort	-	+

Pro and cons of the ternary machine unit and the pump turbine [2]

i. TERNARY MACHINE UNIT PLANT

Ternary machine units consist of a pump, a turbine and a hydraulic converter and are connected through a coupling. The change between turbine and pump operation could be very fast through hydraulic converter at conventional machine units.

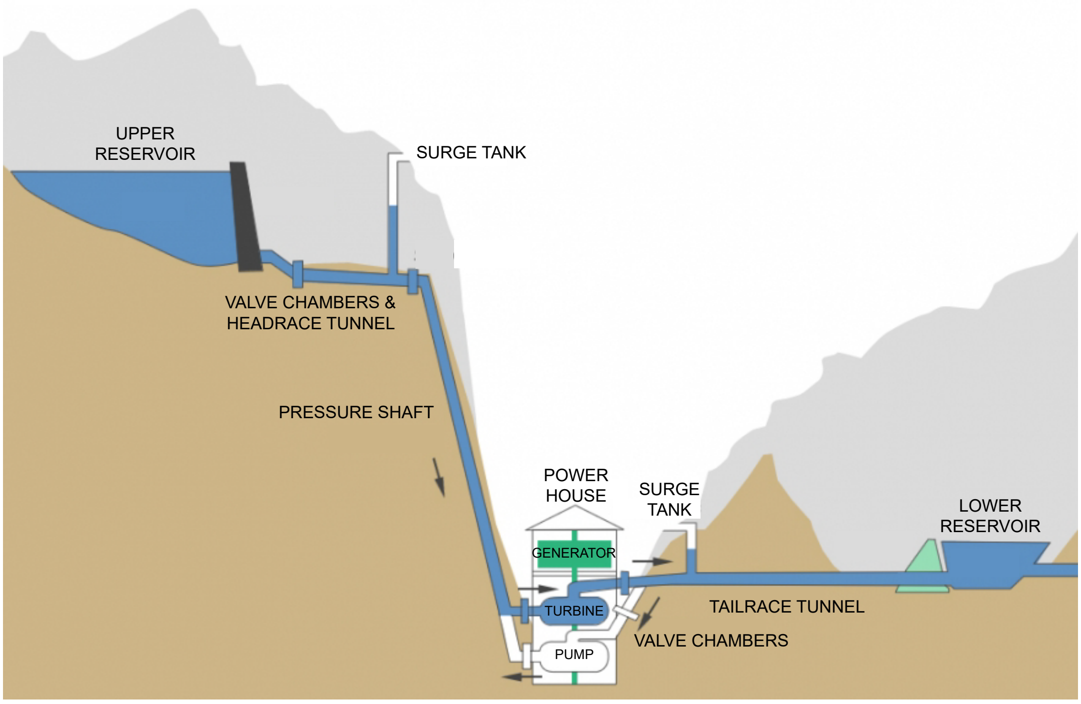
Ternary machine units are useful for locations with gross heads more than 500 m.

The main characteristics for a ternary machine unit are:

- High efficiency in pumping operation
- High efficiency in turbine operation (free choice of the optimum turbine e.g. Pelton turbine at high gross heads)
- Low friction losses through decoupling of pump and turbine
- Very short start-up time (turbine and pump can start-up filled with water using a hydraulic converter)
- Flexibility through shorter operation change times
- Hydraulic short circuit is possible with one machine unit

Conventional machine units normally use synchronous motors due to the better behavior. Primarily applied turbines are Francis turbines or Pelton turbines. Pelton turbines are commonly used at higher gross heads. The gross heads of the Francis turbine and the Pelton turbine overlap partially. [6]

Pelton turbines have a high efficiency at partial-load operation, because of their flat efficiency curve. The efficiency loss is just approximately 5 % due to the low partial-load operation which starts at around 15 % capacity of the turbine. [2]



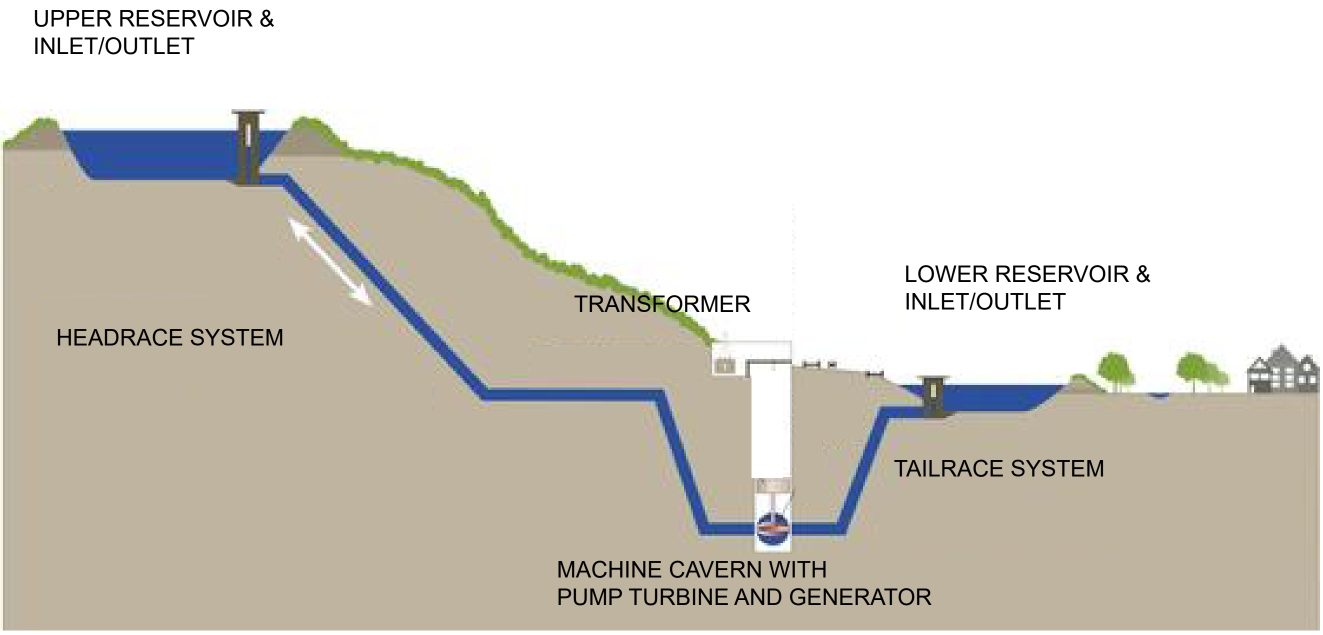
Hydropower scheme with ternary machine unit [8]

ii. REVERSIBLE PUMP-TURBINES

Pump-turbines are directly coupled to the generator and normally consist a Francis turbine. In this case, the Francis turbine is designed to work as turbine or rather pump, depending on the direction of rotation (reversible Francis turbine).

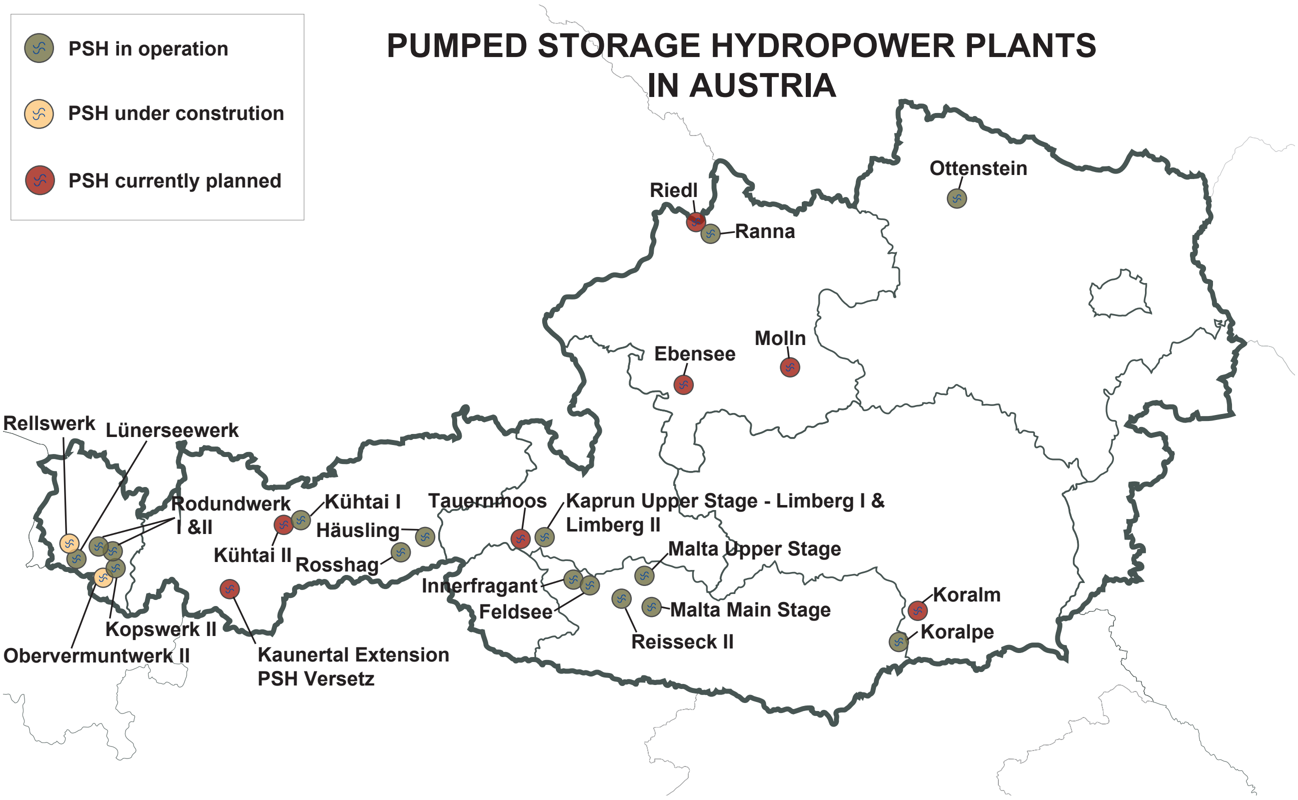
The efficiency of pump turbines and Francis turbines at turbine operation could be around 3 – 4 % less, if they have same rotational speed. Because the pump turbine is designed for pump operation, but this can be compensated through e.g. a fork dive. The table on page 14 shows the pros and cons of the conventional machine unit and the pump turbine with regard to the technical possibilities.

Different pump storage solutions are possible to support the development of renewable energies. The trading in reserve market and network services such as frequency stability often require short switching periods. Beside reversible pump-turbines with fixed speed also ternary units and reversible pump-turbines with variable speed become more important in future projects.



Hydropower scheme with pump turbine [9]

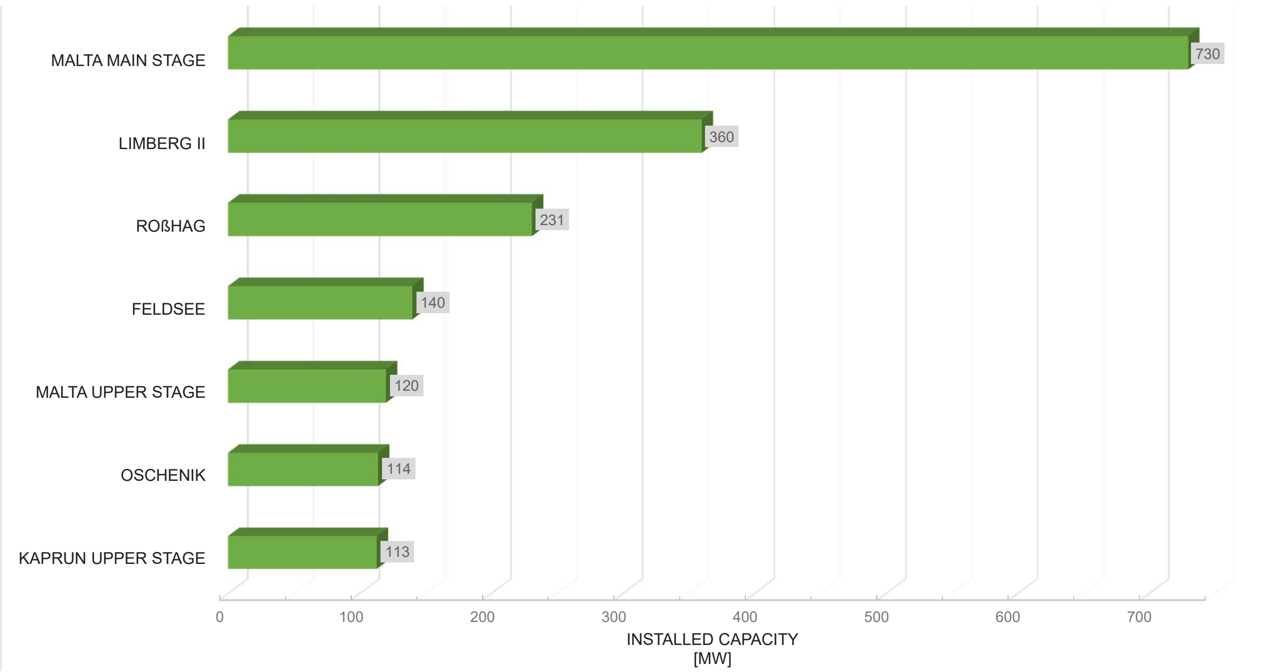
D. PUMPED STORAGE HYDROPOWER PLANTS IN AUSTRIA



Map of Austrians pumped storage hydropower plants [2]

Most of the largest and the highest concentration of pumped storage hydropower plants in Austria are in the alpine region.

The figure below shows the most imported pumped storage hydropower plants with their installed capacity. A small section of some different pumped storage hydropower plants is presented here in the following chapters. E.g. a number of larger plants such as Kaprun (Limberg I and Limberg II) and Kopswerk II but as well some smaller plants such as Ranna and Koralpe.



Important pumped storage hydropower plants in Austria -Installed capacity (turbines) [11]

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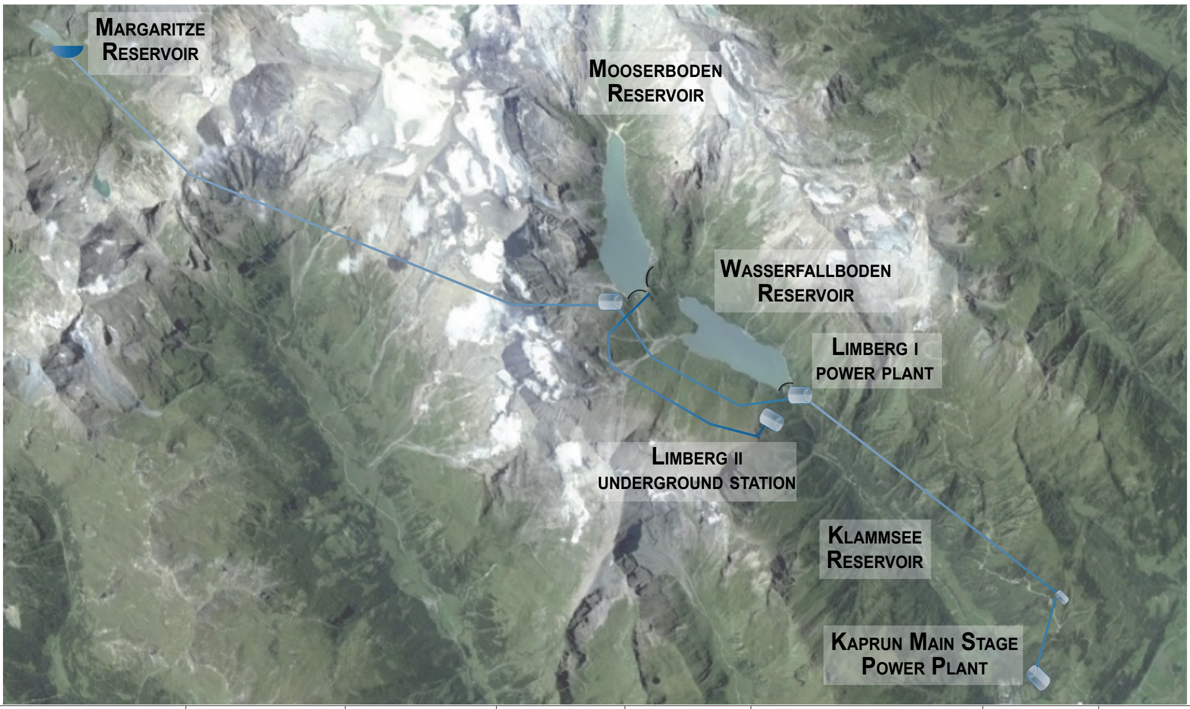
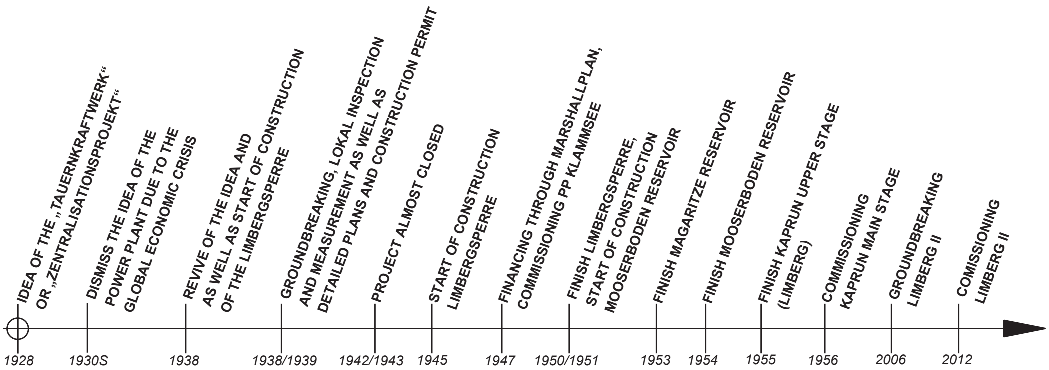
HYDROPOWER PLANTS KAPRUN



	Reservoir Margaritze	**Reservoir** Mooser	**Stage** Limberg II	**Stage** Limberg I	**Reservoir** Wasserfallboden	**Stage** Kaprun Main	**Total**
Live Storage *[10⁶ m³]*	3,2	84,9			81,2		169,3
Mean Gross Head *[m]*			366	366		858,3	1225,3
Discharge **Turbine** *[m³/s]*			144	36		35,7	
Discharge **Pump** *[m³/s]*			72	16,6			
Capacity **Turbine** [MW]	→		480	114	→	240	
Capacity **Pump** *[MW]*	←		480	130	←	-	
Production 1 full filled Reservoir *[GWh]*	70*1				152*2		316*3
Gross Annual Production *[GWh]*			150,4*5			502,6*5	653*6
Energy Content per reservoir filling *[GWh]*	70*1				152*2		386*4
Power Company	Verbund						



DESCRIPTION OF THE TABLE:

The water amount of reservoirs Margaritze and Mooserboden is diverted to the turbines of power caverns Limberg I and II and further lead into the reservoir Wasserfallboden.

The energy values [in GWh] are calculated as:

*1......... $\frac{Live\ Storage\ (Margaritze + Mooserboden)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Limberg\ I\ or. II) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$

*2......... $\frac{Live\ Storage\ (Wasserfallboden)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Kaprun\ Main\ Stage) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$

*3......... $\frac{Live\ Storage\ (Margaritze + Mooserboden + Wasserfallboden)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Kaprun\ Main\ Stage) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$

*4.........formula*3 + formula *1

*5......... values from the literature (including the inflow)

*5......... Sum of Gross Annual Production from the literature (Limberg I and II + Kaprun Main Stage)

The hydropower plant group Glockner-Kaprun consists of Kaprun Upper Stage, which includes the hydropower plants Limberg I and II with the storages Margaritze and Mooserboden, the Kaprun Main Stage with the storage Wasserfallboden, the stream diversions Kaprun west and the power house Klammsee. The processing of the water resources is carried out in two stages. The Kaprun Main Stage with the storage Wasserfallboden got into operation in October 1944, including two machine units each with 45 MW. In 1955 the power plant Kaprun Upper Stage could be put into operation.

MAIN STAGE

The main stage obtains the water from the annual storage Wasserfallboden with a net capacity of 81.2 million m³ and a maximum water level at 1672 m.asl and is created by the gravity arch dam Limberg.

This 120 m high concrete dam was built from 1947 to 1951. Furthermore, the 8.2 km long headrace tunnel, collection works of Zeferet- and Grubbach into the headrace tunnel and the power house Kaprun with 4 horizontal machine units belong to the system of Kaprun Main Stage.

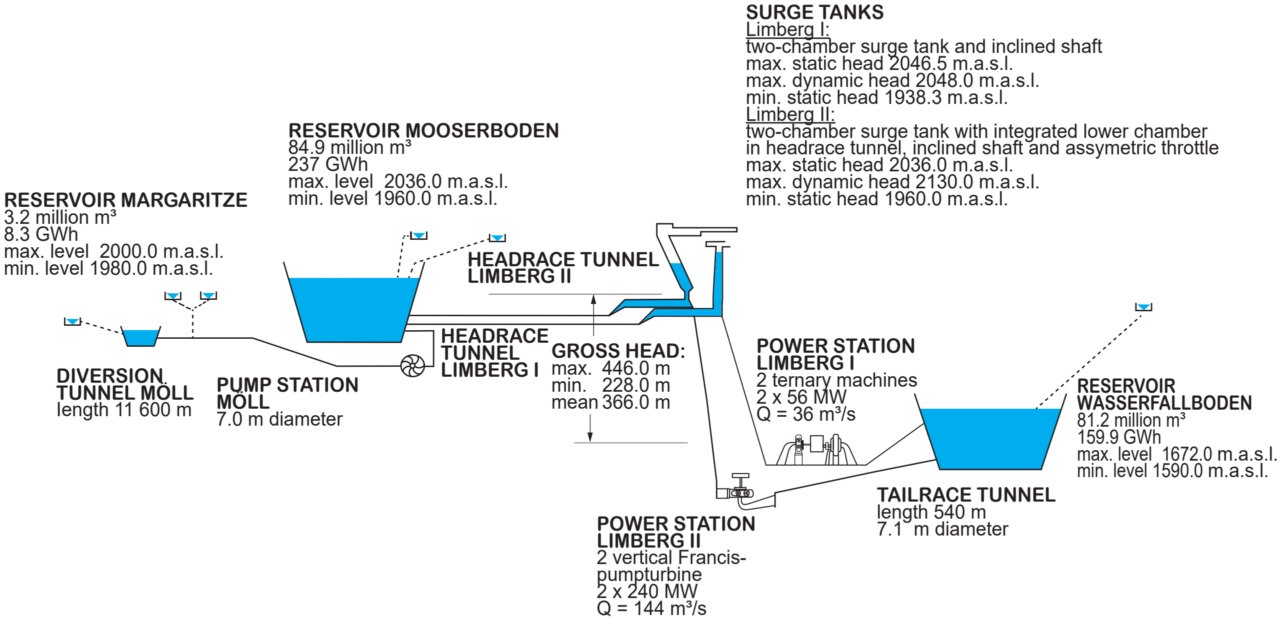
The machine units with a nozzle level of 781 m.asl consist of two Pelton turbines and a generator. The machine units, each with a capacity of 45 MW.

During the construction of the Limberg concrete dam two additional machine units, each with a capacity of 65 MW, were installed. The annual energy production is 503 GWh.

From 2002 to 2004 the four exposed pressure pipes were replaced by a 1500 m long steel lined pressure shaft. In addition, a new service chamber was built.

The facilities of the Main Stage also consist of an additional power system with the reservoir Klammspeicher, a 430 m long power water way and two machine units in the power house Kaprun, each with a capacity of 264 kW.

The reservoir Klammspeicher has a capacity of 0.2 million m³ and a maximum water level at 847 m above sea level, created by the 21 m high gravity dam "Bürg". The machine units provide the basis for the black start capability of the entire power plant group.



Hydropower Scheme Limberg I and Limberg II

UPPER STAGE

The total annual capacity of the Upper Stage is around 166 GWh. It consists of the annual storage Mooserboden, the week storage Margaritze, the intake Leiterbach and Käferbäche, the pump station Möll, the transition tunnel from Magaritze reservoir the collecting of the Ebmatten- and Wielingerbach, a 5 km long power water way and the power house Kaprun Upper Stage.

The annual storage Mooserboden has a net capacity of 84.9 milion m³ and a capacity level of 2036 m.asl. It is formed by the Mooser dam, a 107 m high gravity dam, and the Drossen dam, a 112 m high arch dam, built from 1951 to 1955.

The transition of the river Möll includes the week storage Margaritze with a net capacity of 3.2 million m³ and a capacity level of 2000 m.asl, formed by the Möll dam, a 56 m high arch dam with a 37 m high concrete plug of the Möll canyon, and the 39 m high gravity dam Margaritze.

The pump station Möll makes it possible to pump water from the Magaritze reservoir into the reservoir Mooserboden if the water level is higher than in the reservoir Margaritze.

The power house Kaprun Upper Stage is situated at the foot of the Limberg dam with two horizontal ternary machine units which consist of motor generator, turbine and pump.

The collection works of the Hirzbach from the east-neighboring catchment area of the Fuscher Ache with a 4.9 km long tunnel was built between 1971 and 1973. The energy production of the power station Kaprun Main Stage was increased by 25 GWh. Between 1982 and 1986 the collection work Kaprun west was constructed.

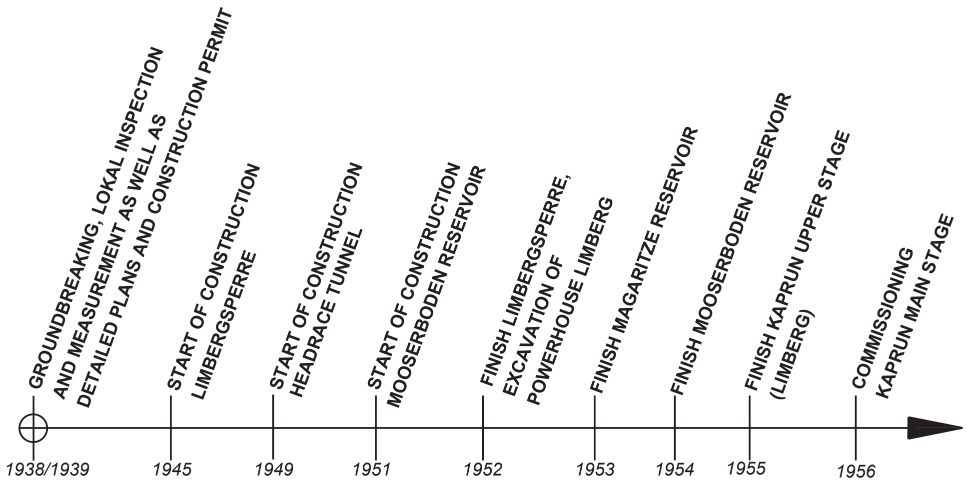
The runoff of the west neighbouring Mühl- and Dietersbach valley is collected at an elevation of 1605 m.asl and transported through a 6 km long tunnel as well as through the pump station Maiskogel into the pressure tunnel towards the power house Kaprun.

Reservoir Mooserboden with the view of the Mooser dam [1]

KAPRUN UPPER STAGE - LIMBERG I

PUMPED STORAGE HYDROPOWER

Commissioning	1956		Live Storage **Mooserboden**	84.9	[Mio. m³]
Machine type	Francis turbine with storage-pump		Live Storage **Wasserfallboden**	81.2	[Mio. m³]
Headrace Surge Tank	two-chamber system with rising shaft		**Mean Gross head**	366	[m]
Discharge **Turbine**	36	[m³/s]	Installed capacity **Turbine**	122	[MW]
Discharge **Pump**	16.6	[m³/s]	Installed capacity **Pump**	130	[MW]
Live Storage **Margaritze**	3.2	[Mio. m³]	**Company**	Verbund	



PLANT DESCRIPTION

Verbund's hydropower plant Kaprun Upper Stage - Limberg I is a pumped storage hydropower plant in Salzburg and was built from 1950 to 1955. The pumped storage hydropower plant Kaprun Upper Stage – Limberg I uses the tributaries of their own catchment area, the transition Möll as well as the creeks Ebmattenbach and Wielingerbach of the Kapruner-Ache between Mooserboden and Wasserfallboden.

The Mooserboden is a wide and flat high valley and is the upper stage of the Kapruner-Ache. The east Drossen dam and the west Mooser dam form the storage Mooserboden. The storage Mooserboden has a maximum operation level of 2036 m.asl and a minimum operation level of 1960 m.asl.

The storage capacity of the storage Mooserboden is around 84.9 million m³ with a gross head of 366 m to the reservoir Wasserfallboden. The own tributaries were not enough to fill the year storage, therefore transition Möll was additionally installed.

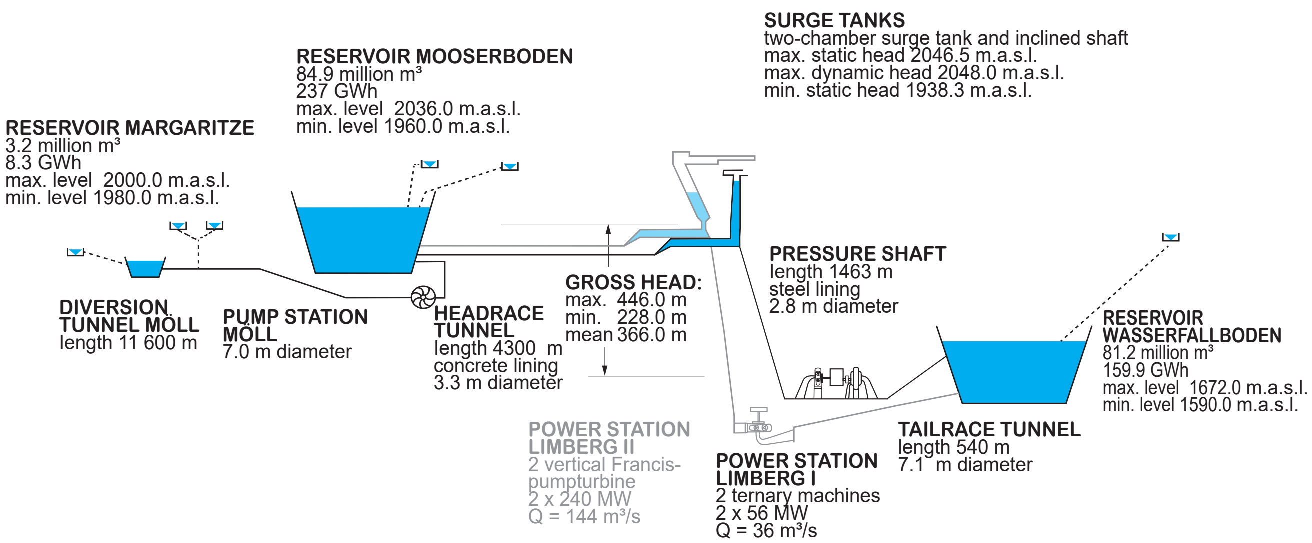
The transition Möll generally consists of the daily storage Margaritze with a storage capacity of around 3.2 million m³, the 11.6 km long transition tunnel Möll/Margaritze and the pump station at Mooserboden.

The daily storage Margaritze gets water from the creek Leiterbach and the creeks Käferbach flow into the transition Möll on half way. The total catchment area at the upper stage amounts 99.4 km². The 5.1 km long headrace system leads through the pump station Möll and then passes through the right slope of Wasserfallboden.

It consists of the intake, the 3.9 km long headrace tunnel followed by the surge tank and the 463 m long lined pressure shaft.

The following distribution pipeline leads to the power house Limberg at the airside foot of the Limberg dam. Two tunnels through the dam pass the water to the storage Wasserfallboden. In pumping operation, the two storage-pumps reduce the water to the storage Mooserboden.

The power house consists of two Francis turbines with a capacity of each 61 MW and two radial storage-pumps with a capacity of each 65 MW. In a average year, the annual production is around 150.4 GWh.



Hydropower Scheme Limberg I

Construction phases of the Limberg dam [5]

RESERVOIR MANAGEMENT

Around 50 % of the stored water in the Mooserboden and Wasserfallboden reservoir come from the south of the Alps and consists mainly of melted ice and snow from the Pasterze Glacier of the Großglockner.

The water is stored in the Margaritze reservoir with the Margaritze dam and the Möll dam, in the Mooserboden reservoir with the Drossen dam and the Mooser dam and last but not least in the Wasserfallboden reservoir with the Limberg dam.

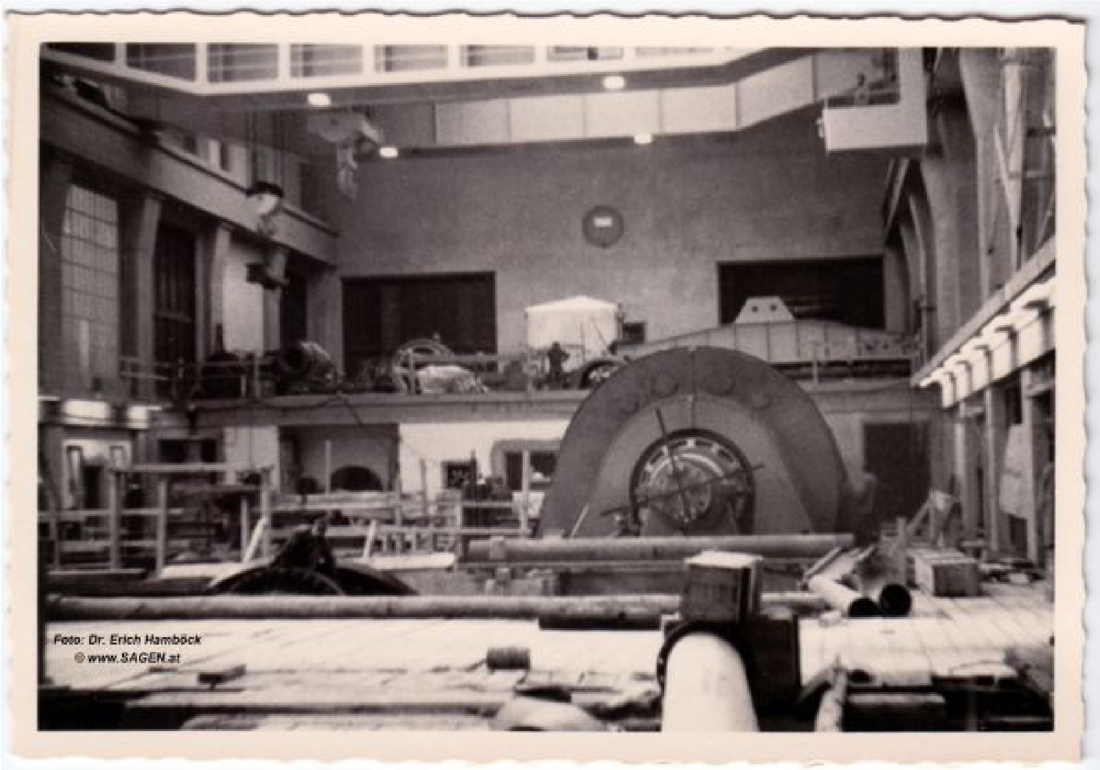
Generally, in pumping operation the Kaprun Upper Stage pump the subjected water from the Wasserfallboden reservoir into the Mooserboden reservoir.

At standstill the pump and the motor or generator turbine should be coupled and against closed pump ring valve run up to nominal speed with the turbine. Another requirement is the operation in the hydraulic short circuit.

The so called hydraulic short circuit is a hydraulically parallel circuit of the pump and the turbine on the same shaft.

POWER WATER CONDUIT

The conduit system consists of a headrace tunnel, a surge tank and an steel lined pressure shaft. The pressure shaft has an inclined and a horizontal section and is situated after the upper valve chamber.



Construction of the power house Limberg I [4]

INLET / OUTLET BUILDING MOOSERBODEN

The intake building is situated around 100 m before the Drossen dam. It has two inlet openings equipped with fine racks. Gates for the intake line are steel bulkheads.

The catchment area of storage Mooserboden includes the tributaries Leitenbach, Margaritze, Käfertal and Mooserboden. The intake line lead this water to the headrace system, that start at the pumping station Möll.

PUMPING STATION MÖLL AS A PART OF THE HEADRACE TUNNEL

The Margeritze reservoir, the top reservoir of the Kaprun Upper Stage, is impounded by the Margaritze and the Möll dam.

The Möll diversion tunnel, the Käferbach diversion and the Möll pump station is situated between the Margaritze and the Mooserboden reservoir. Water is moved through the Möll pump station tunnel depending on the water level of the reservoirs.

The Möll pump station consists of two pump units. Several valves enable the various operation modes of the Kaprun Upper Stage.

The machine and pipeline installations are designed for the following operation modes:

- Turbine operation Limberg from the storage Mooserboden into the storage Wasserfallboden
- Pumping operation from the storage Limberg into the storage Wasserfallboden
- Pumping operation Möll from the storage Margaritze into the storage Mooserboden
- Transition from the storage Margaritze into the storage Mooserboden, if the water level conditions allow
- Turbine operation from the storage Margaritze into the storage Limberg

HEADRACE TUNNEL

Headrace Tunnel		
Inner diameter	3.3	[m]
Excavated diameter	4.0-4.2	[m]
Length	4300	[m]

The around 4.3 km long headrace tunnel starts at the pumping station Möll with a diameter of 3.3 m and raises at the intake side with 2 ‰ along 2.2 km until the ventilation windows Wielinger.

The following section decreases with 5.29 ‰ until the upper valve chamber. The headrace tunnel has a hoof print profile with a clear span from 4 m to 4.2 m and the clear tunnel profile has a clear diameter of 3.3 m. The lining is a 30 cm concrete and a 5 cm thick armored inner shotcrete. The headrace tunnel has a flow rate of 36 m^3/s.

SURGE TANK & UPPER VALVE CHAMBER

The surge tank is designed as a two-chamber surge tank with rising shaft, it is located after the headrace tunnel and 20 m before the upper valve chamber. The upper valve chamber is situated at the beginning of the pressure shaft.

The lower chamber of the surge tank has a circular profile with diameter of 3.5 m and a length of 75 m. The lower chamber of the surge tank has a horse shoe profile with a clear span of 5 m and a length of 90 m.

The lined rising shaft has a circular profile with a diameter of 3.1 m and a gradient of 45 ° over a length of 148 m. The upper chamber level is at 2046 m.asl. The surge tank is designed for shut-off loading of turbine operation with a maximum operation level of 2035 m.asl at the storage Mooserboden. The upper valve chamber close to the beginning of the pressure shaft consists of butterfly valve with a diameter of 2.8 m.

PRESSURE SHAFT & LOWER VALVE CHAMBER

Pressure Shaft		
Inner diameter	2.9-2.8	[m]
Excavated diameter	3.8	[m]
Length	463	[m]

The steel lined pressure shaft has a length of 463 m. The diameter decreases from 2.9 m to 2.8 m and to 2.7 m (from top to bottom). The lining ranges between 18 mm and 28 mm. The harsh concrete is around 30 cm thick. A 200 m long tunnel connects the pressure tunnel and the lower valve chamber.

The steel lining of the tunnel has a thickness between 26 mm and 28 mm and an inner diameter of 2.5 m. The tunnel is followed by two distribution pipelines after 178 m. The distribution pipelines have a clear diameter of 1.7 m. They can be closed via two spherical valves with a diameter of each 1.7 m. The installed double Ventrui tubes measure the discharge at each spherical valve. The distribution pipelines lead

Kaprun Upper Stage - Mooserboden and Wasserfallboden reservoir [5]

Ternary machine unit of Limberg I [5]

POWER HOUSE

The power house Kaprun Upper Stage – Limberg I built at the foot of the Limberg dam. The transverse section is 28.5 m deep and 107 m long. Below the compound site are the turbine and pumping pipelines, which lead through the Limberg dam. The pipelines have a diameter of 2.2 m.

The side wing that span six floors, harbour some workshops and storage areas, cable floor, control room and the necessary offices and common rooms. The two ternary machine units are located at the machine hall with a length of 59.6 m, a width of 22.4 m and a height of 15.7 m.

The pump distribution pipeline of the fist machine unit has ring valve and can used as a second bottom outlet of the storage Wasserfallboden. The stilling basin not only to convert energy is also used as cooling water reservoir for the generators.

Around 10000 m³ rock had been excavated as well as around 42000 m³ concrete were necessary to build the power house Limberg. A 110-kV double-circuit line transports the produced energy to the open-air switchyard. The two machine units with horizontal shaft are located at the power house Limberg.

The power house with ternary machine units of Limberg I [5]

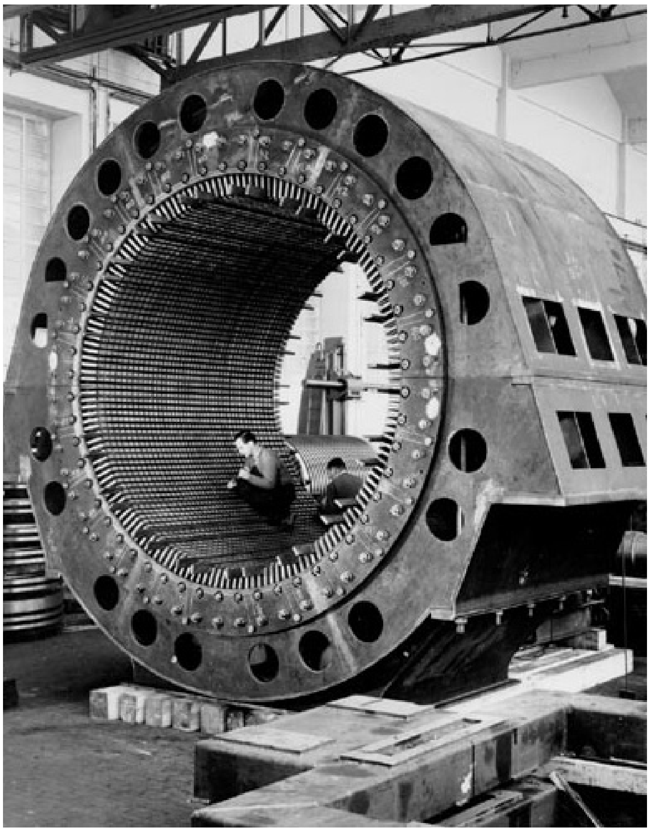
MACHINE UNIT

The two horizontal machine units at the power house Limberg have an installed capacity of each 112 MW. A machine unit consists of a Francis turbine, a motor generator, gear coupling and a two-stage, double-entry pump.

Each turbine has a capacity of around 56 MW. The water from two Francis turbines by Andritz company can used to further produce electricity by the Kaprun Main Stage. The two-stage, double-entry pumps transport the water from the storage Wasserfallboden into the storage Mooserboden and have a capacity of each 65 MW.

Both pumps are as well produced by Andritz company. Two synchronous generators are installed. Inside the power house is a 110-kV indoor switchyard and the electricity is transported by the 110-kV double-circuit line to the outdoor switchyard Kaprun.

In 2012 the Limberg scheme was extended by the pumped storage hydropower plant Limberg II.



Generator of Limberg I [4]

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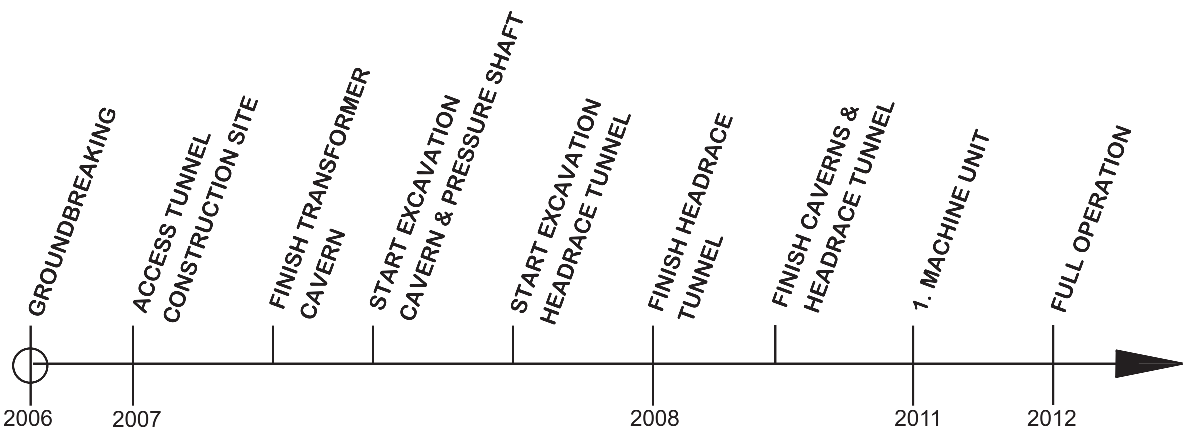
LIMBERG II

PUMPED STORAGE HYDROPOWER

Commissioning	2008		Live Storage **Mooserboden**	84.9	[Mio. m³]
Machine type	two reversible Francis pump turbine		Live Storage **Wasserfallboden**	81.2	[Mio. m³]
Headrace Surge Tank	trottled two-chamber system with integrated lower chamber in headrace tunnel		**Mean Gross head**	366	[m]
Discharge **Turbine**	144	[m³/s]	Installed capacity **Turbine**	480	[MW]
Discharge **Pump**	72	[m³/s]	Installed capacity **Pump**	480	[MW]
Live Storage **Margaritze**	3.2	[Mio. m³]	**Company**	Verbund	



PLANT DESCRIPTION

Verbund's hydropower plant Kaprun – Limberg II is an open-loop pumped storage hydropower plant and situated close to the village of Kaprun, province of Salzburg. It was constructed from 2006 to 2012. It is situated in the same area as the existing pumped storage hydropower plant Kaprun Upper Stage - Limberg I and it raises the output capacity of the Kaprun hydropower plant group from 353 MW to 833 MW.

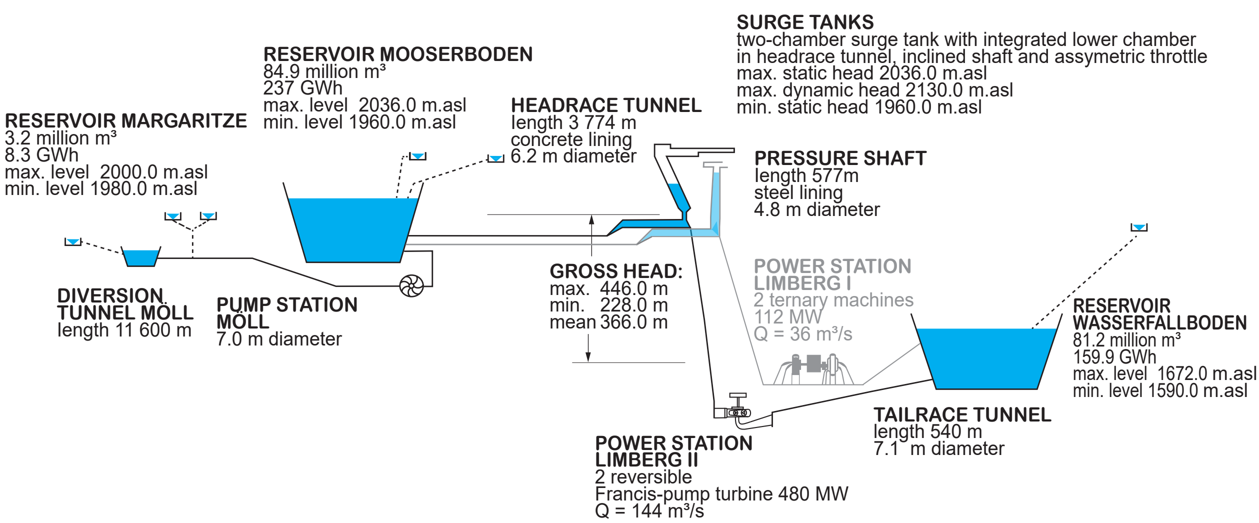
With the height difference between the two reservoirs Wasserfallboden and Mooserboden it can be used to balance on energy of around 32 GWh. The facility consists of the intake in the Mooserboden reservoir beneath the Drossen dam, the power waterway in the right valley flank, the surge tank, the steel lined pressure shaft and the machine cavern next to the existing power house of Limberg I.

The tailrace tunnel leads from the power cavern to the reservoir Wasserfallboden. The underground power plant can be divided into the power cavern and the power transformer cavern. The dimensions of the power cavern are 62/25/43 m (length/width/height). The smaller transformer cavern is located in a distance of 35 m. The power house Limberg I and the machine cavern Limberg II are connected by two connecting tunnels in the middle and south and by the access tunnel in the north.

The machine cavern consists of the turbine level with two reversible Francis pump turbines and a hydraulic valve in the lower region, the generator level in the middle and the machine hall at the top.

Operation rooms for guidance and control equipment, excitation, emergency base, sanitary rooms and the main stairs occupy the west side of the cavern. In addition, there are two escape staircases at the north and south ends of the cavern. The transformer cavern with the dimensions of 61/15/16 m (length/width/height) was excavated parallel to the machine cavern. The cavern is equipped with two 380 kV generator transformers and the SF6 transformers are located in a separate room.

The inlet / outlet at the Mooserboden reservoir is located between the Drossen dam and the Mooser dam in the rock formation Höhenburg. It is followed up by the 32/19/22 m large valve chamber Höhenburg and the headrace tunnel. The surge tank is located close to the existing surge tank of the power plant Limberg. It is constructed as a two-chamber surge tank with an upper chamber, a 45° inclined rising shaft and a flow-through lower chamber. The 45° inclined pressure shaft has a length of 577 m. The 540 m long tailrace tunnel leads from the tailrace side bifurcation to the inlet / outlet Wasserfallboden.



Hydropower scheme of Limberg II

RESERVOIR MANAGEMENT

The pumped storage hydropower plant Limberg II expands the power balancing possibilities by using the existing reservoir volume of the storage system Kaprun.

SPECIFICS OF LIMBERG II:

- An favorable topology with a large upper and lower reservoir
- A system of power plants with a significant natural inflow
- A large range of possible heads in utilization of the buffering options and therefore strongly fluctuating flow rates and performance
- Parallel operation with the existing power plant Kaprun Upper Stage
- Trial variety of auxiliary grid services

OPERATION

The simulation results for Limberg II have shown strongly pronounced week cycles of the management due to the price pattern in the early years: A part of the water, which is taken on weekdays during the day is pumped back into the upper reservoir every night.

Over the weekend, a considerably larger amount of water is pumped back than taken out. This cycles require about 20 % of the total buffer volume. For the season shift, the remaining storage volume is used.

But in the first years of operation the peak price dropped as well as the spread between base load and peak load. As well as the increased installation of photovoltaics has diminished the noon demand peak.

The impact of the economic crisis is reflected lower capacity utilization and lower revenues in the first years of operation. Such effects must be taken into account by risk calculations in investment projects with an extremely long calculation time, as is generally the case of hydropower plants.

Wasserfallboden and Mooserboden reservoir [6]

Construction of the headrace tunnel of Limberg II [3]

POWER WATER CONDUIT

The headrace tunnel of the pumped storage hydropower plant Limberg II consists of the inlet / outlet Mooserboden, the inlet tunnel, the valve chamber Höhenburg, the headrace tunnel, the pressure shaft, the tailrace tunnel with the tailrace gate chamber and the inlet / outlet construction Wasserfallboden.

It has a length of about 5.4 km and is designed for a flow of 144.0 m³/s.

INLET / OUTLET STRUCTURE *MOOSERBODEN AND WASSERFALLBODEN*

Since 1970 an already existing structure was situated at the area of the new inlet / outlet structure Mooserboden. The old structure had to be removed for the reconstruction of the new structure.

The construction of the inlet / outlet structure Wasserfallboden was difficult because of difficult access to the area. In 2010 the concrete structure was manufactured. The construction works were first carried out at the reservoir Mooserboden and afterwards at the reservoir Wasserfallboden.

INLET TUNNEL

The 254 m long inlet tunnel was excavated by drill and blast tunneling method. It consists of a short horizontal section, a vertical shaft and another horizontal section. Both vertical bends were lined with shotcrete while the other tunnel sections have a concrete-lining.

The inner diameter varies between 5.8 m and 7.0 m. The horizontal tunnel section in front of the valve chamber crosses the main grout curtain of the Drossen dam, the second part was constructed with steel lining with an inner diameter of 5.7 m.

VALVE CHAMBER HÖHENBURG

The valve chamber Höhenburg can be accessed over a 581 m long access. The valve chamber with the dimensions length/weigh/height = 32 m/19 m/22 m was excavated by drill and blast.

It contains two butterfly valves that function as the security shutoff devises in case of leakage of the pressure tunnel or the pressure shaft and prevent an outflow of the reservoir Mooserboden. At the headwater side of the valve chamber the headrace pipeline is led in a 15 m long pipe for the ultrasonic flow measurement.

Scale model [M 1:30] of the surge tank of Limberg II at TU Graz

In the valve chamber itself the water flows in a free steel pipe with an inner diameter of 4.9 m. An overhead crane with a load capacity of 1300 kN is installed for maintenance works. The cavern is lined with shotcrete.

HEADRACE TUNNEL

Headrace Tunnel		
Inner diameter	6.2	[m]
Excavated diameter	7.0	[m]
Length	3774	[m]

The headrace tunnel has a length of 3774 m and has an inclination of 0.45 %. The track alignment has been chosen to run parallel in the first section downslope of the existing headrace tunnel by a distance of 100 m.

The first, about 300 m long section in the area of the Drossen dam, where only a very small mountain coverage of minimal 1.7 m is given, was constructed with steel lining with an inner diameter of 5.0 m. Afterwards, the 3.4 km long tunnel route was excavated by an open hard rock TBM (D=7.0 m, L=240 m).

The mountain coverage in this section is about 150 m to 450 m. After the steel lined section, a transition zone follows with an inner diameter of 6.2 m with concrete lining and an exterior foil sealing. The remaining section is lined with concrete (D=0.4 m) without sealing. The maximum static pressure head at maximum operation level in the reservoir Mooserboden amounts to 141 m head.

The dynamic pressure head at up-surging in the surge tank amounts to about 218 m head. The water pressure inside the tunnel causes tension stresses in the concrete lining. For the external pressure the mountain water level is decisive.

The mountain water level causes a surrounding hydrostatic pressure on the concrete shell.

The concrete ring was designed to internal and external pressure performed by the method of Seeber 1989.

A value of 10000 N/mm² could be scheduled for the rock deformation modulus. The radial pre-stressing injection was adapted to the inner pressure to activate the mountain participation and avoid a cracking of the concrete lining by the so built bearing ring.

SURGE TANK

The surge tank is situated at the transition pressure tunnels and pressure shaft, the throttled two-chamber surge tank is provided to ensure a stable power plant operation. The lower chamber is integrated into an extension of the headrace tunnel.

The surge tank shaft is constructed as extension of the inclined shaft and is connected via a asymmetric throttle to the lower chamber. The upper chamber runs from the shaft head to the aeration building which is located close to the existing surge tank aeration building.

A hydraulic model test was carried out at the hydraulic laboratory at TU Graz to test the throttle and the functionality of this hydraulic element. The distribution pipeline, that includes two short lined shafts and a shaft with atmospheric exposed distribution pipes, that leads to the machine cavern.

PRESSURE SHAFT

Pressure Shaft		
Inner diameter	4.8	[m]
Excavated diameter	5.8	[m]
Length	770	[m]

The steel lined pressure shaft has a length of 770 m, is inclined by 45° and has an inner diameter of 4.80 m. It is subsequent to a bend.

An open hard rock TBM (D = 5.8 m, L = 90 m) was used to excavate. The shaft has an inner steel lining and the area between outbreak embrasure and the lining was filled with concrete.

TAILRACE TUNNEL AND TAILRACE GATE CHAMBER

The downstream distribution pipeline leads to the tailrace tunnel that has a diameter of 6.80 m and is around 400 m long. The distribution section is steel lined and the section after the downstream valve chamber is lined with in-situ reinforced concrete.

The tailrace tunnel crosses under the existing pressure shaft of the upper plant and rises by 19 % to the inlet / outlet construction of the reservoir Wasserfallboden. The tailrace gate chamber is equipped with a roller gate.

Mooserboden reservoir in Winter [10]

Machine hall of Limberg II [11]

MACHINE CAVERN

Preliminary investigations showed that a division into a machine cavern and a transformer cavern has economic and operational advantages. In the 62 m long, 25 m wide and 44 m high machine cavern, the machine sets are housed with the valves and all the equipment directly associated to the machine as well as auxiliary equipment.

Two transformers, two converter transformers and the static frequency converter of the start-up control, the 380-kV SF6 switchgear and the middle voltage switchgear are installed in the smaller transformer cavern. Two spherical valves with a nominal width of 2.2 m and suitable for emergency shut down were installed as headrace-cutoff devices on the high pressure side within the cavern.

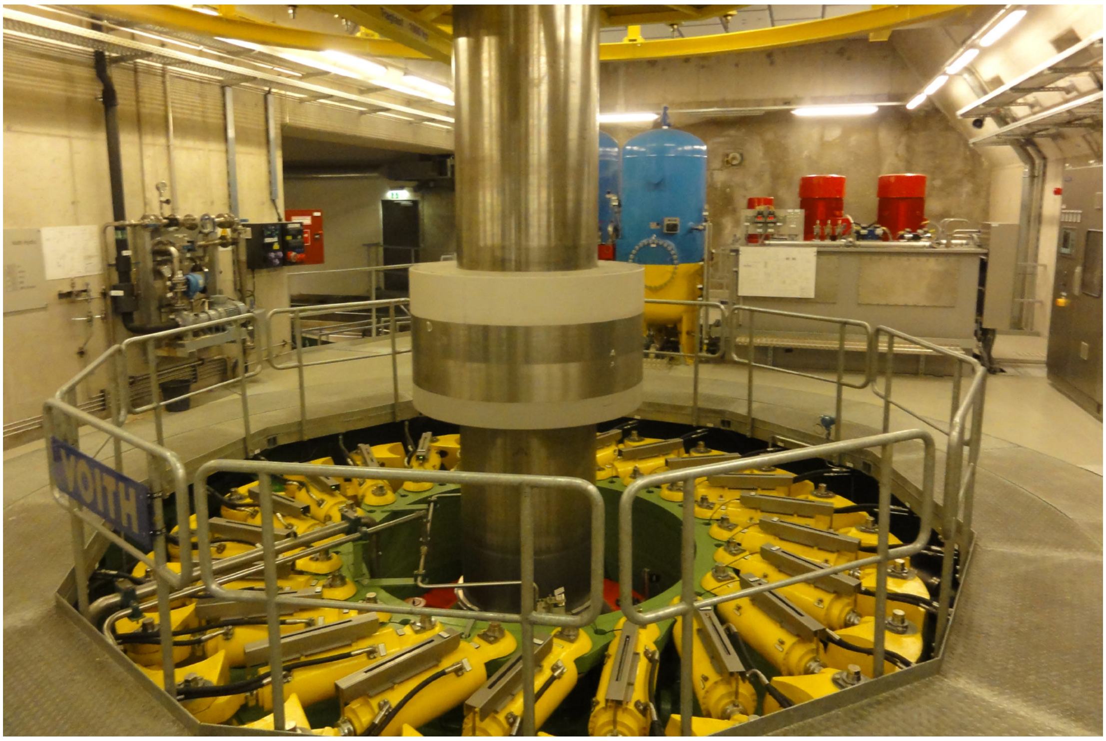
On the low pressure side two suction pipe-sluice gates were installed as headrace-cutoff devices. To manipulate the various components of the machinery in the cavern two cranes were installed, each with 180 t capacity in the machine hall. Both units will run as vertical, reversible Francis pump turbines with directly coupled synchronous motor generators.

The maximum power in pumping and turbine operation is 240 MW per machine unit, motor generators are designed for a capacity of 270 MVA per unit. The pump starts with dewatered running wheel in frequency starting with a static 12 MW frequency converter, which is fed through the block transformers from the 380 kV grid.

The dewatering of the pump turbine is performed by compressed air facility. The motor generators are connected to the associated 270 MVA transformers in the separated transformer cavern.

The generator output power cables, including the associated switching and auxiliary facilities are arranged in two parallel connecting corridors between power and transformer caverns. The SF6-insulated 380 kV indoor switchgear is housed in the transformer cavern.

The energy is transported via a 380 kV line towards the switchyard Kaprun and further across the Schaufelberg towards the transformer station Tauern.



Generator room of Limberg II [4]

MACHINE UNIT

Two vertically installed reversible Francis pump turbines with an intake capacity of 72 m³/s, supplied by Voith Hydro GmbH & Co. KG (St. Pölten), produce an output of 240 MW per unit in turbine mode at a nominal load of 370 m and also handle a maximum of 240 MW per unit in pump mode.

Two motor generators of Andritz Hydro supply 270 MVA in normal operation and need a power of 260 MW in pump operation. The rotor with a total weight of 340 t represents the heaviest single component of the system. Each machine set has an overall height of 18.5 m with the pump turbine and the overlying generator.

The two 2.2 m wide spherical valves from Alstom provide the necessary shutting off of the pressure lines.The 270 MVA transformers with design voltage levels of 14.5 / 420 kV are products of Siemens and have an empty weight of 220 t.

Two overhead cranes with a maximum capacity of 180 / 10 t were installed in the machine hall, two 60 t-ceiling cranes were installed at the turbine level.

View at the machine hall of Limberg II [11]

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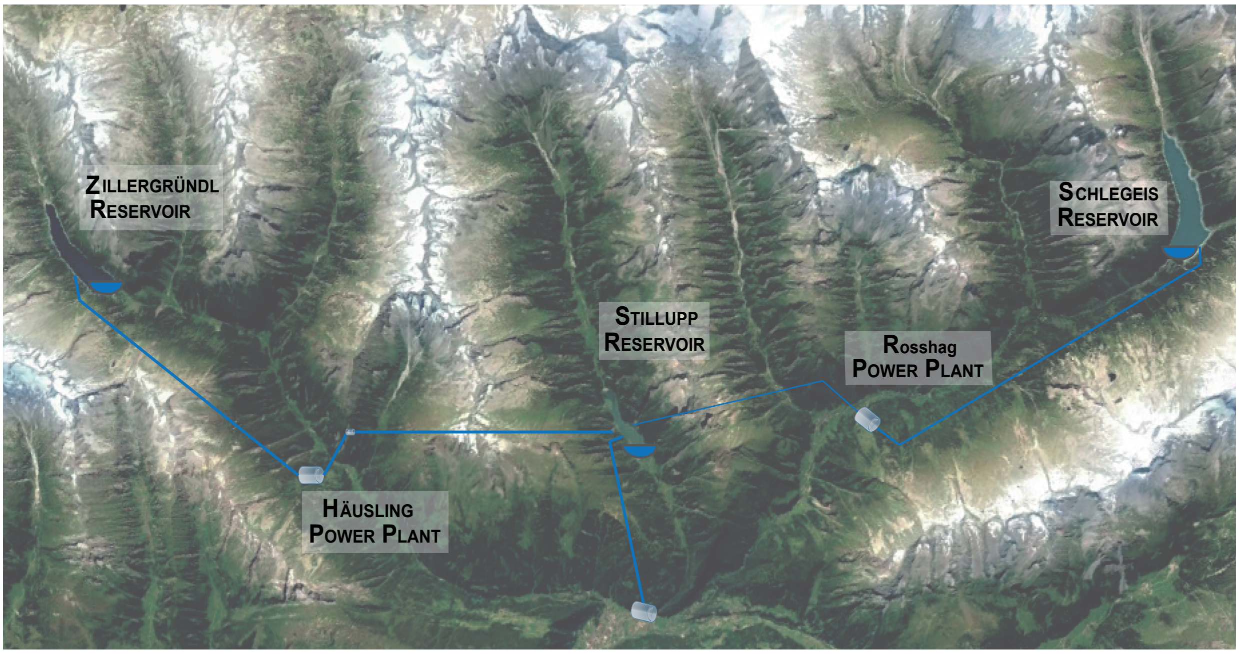
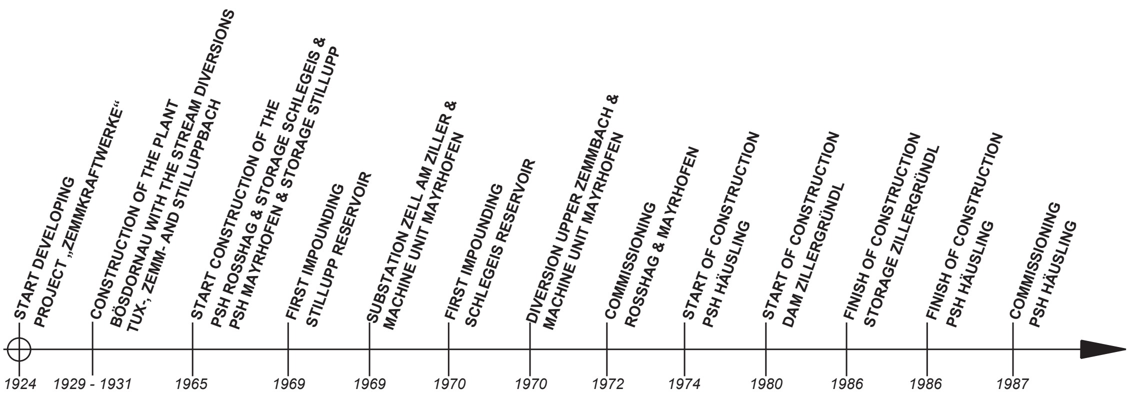
HYDROPOWER PLANTS ZEMM-ZILLER



	Reservoir Zillergründl	Reservoir Schlegeis	Stage Häusling	Stage Roßhag	Reservoir Stillup	Stage Mayrhofen	Total
Live Storage [10⁶ m³]	86,7	126			6,8		220
Mean Gross Head [m]			696	630		470	1099
Discharge **Turbine** [m³/s]			65	52		92	
Discharge **Pump** [m³/s]			43	36			
Capacity **Turbine** [MW]	→	→	360	231	→	345	
Capacity **Pump** [MW]	←	←	360	240	←	-	
Production 1 full filled Reservoir [GWh]	131*1	173*1			7*2		225*3
Gross Annual Production [GWh]			179.4*5	313.2*5		671.2*5	1164*6
Energy Content per reservoir filling [GWh]	131*1	173*1			7*2		232*4
Power Company	Verbund						



DESCRIPTION OF THE TABLE:

The water amount of reservoirs Zillergründl to Schlegeis is channeled to the hydraulic machines to the powerhouses Häusling to Roßhag and further lead into the reservoir Stillup.

The energy values [in GWh] are calculated as:

*1.........
$$\frac{Live\ Storage\ (Zillergründl\ or\ Schlegeis)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Häusling\ or\ Roßhag) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$$

*2.........
$$\frac{Live\ Storage\ (Stillup)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Mayrhofen) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$$

*3.........
$$\frac{Live\ Storage\ (Zillergründl + Schlegeis + Stillup)[10^6 * m^3] * 9.81 \left[\frac{m}{s^2}\right] * Mean\ Gross\ Head\ (Mayrhofen) * Applied\ Efficiency(0.8)}{(3600[\frac{s}{h}] \times 10^6)}$$

*4.........formula*3 + formula *1

*5......... values from the literature (including the inflow)

The power plant group Zemm-Ziller is located in the province of Tyrol. The extensive sources of the Ziller river, Tuxbach river, Zemmbach - and Stillup creeks are located at 3000 m.asl and are used to generate electricity by this power plant group.

It consists of the two upper stages, the pumped storage hydropower plant Roßhag and pumped storage hydropower plant Häusling, with the storages Schlegeis and Zillergründl and the main stage Mayrhofen with the storage Stillup.

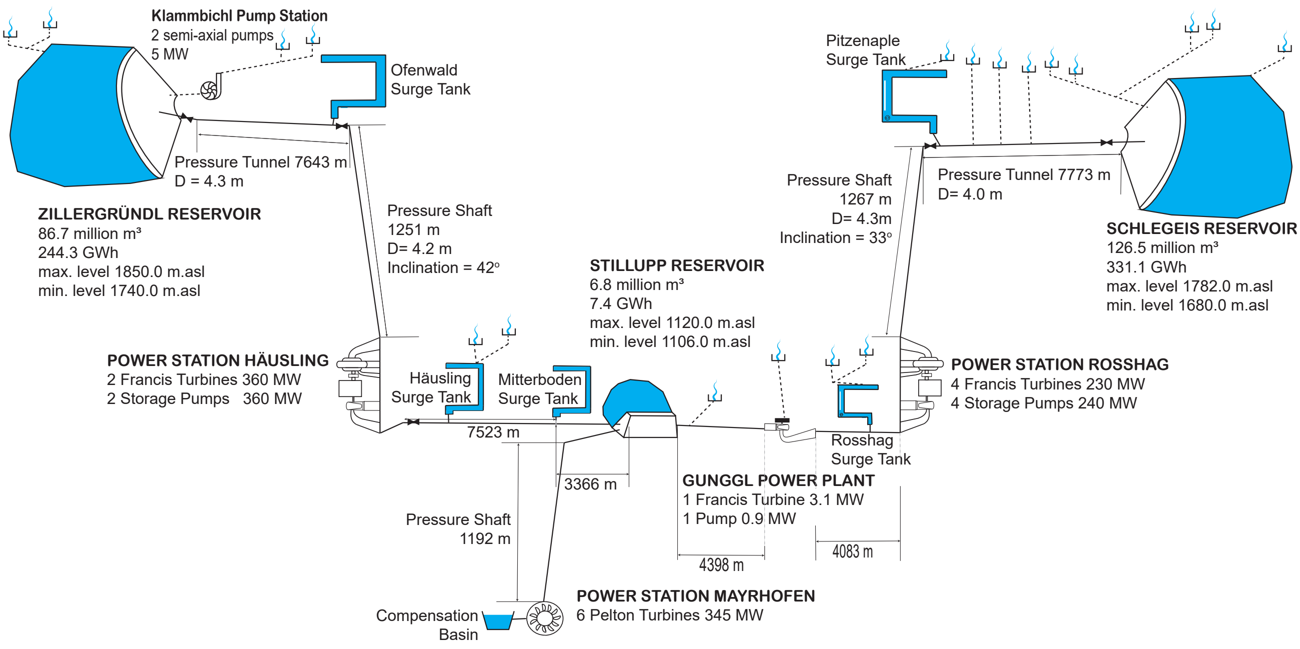
The run-of-river plants Gunggl and Tuxbach as well as the storage plant Bösdornau are also associated with the power plant group. In 1930, the Zillertaler Kraftwerke AG put the storage power plant Bösdornau and the run-of-river plant Tuxbach into operation.

Later in 1934, the Tiroler Wasserkraftwerke AG (TIWAG) purchased these plants. In 1939, the TIWAG expanded the plants through a stream diversion of the Stillup-creek. The pumped storage hydropower plant Roßhag and the storage hydropower plant Mayrhofen were built in 1965 and extended in 1976.

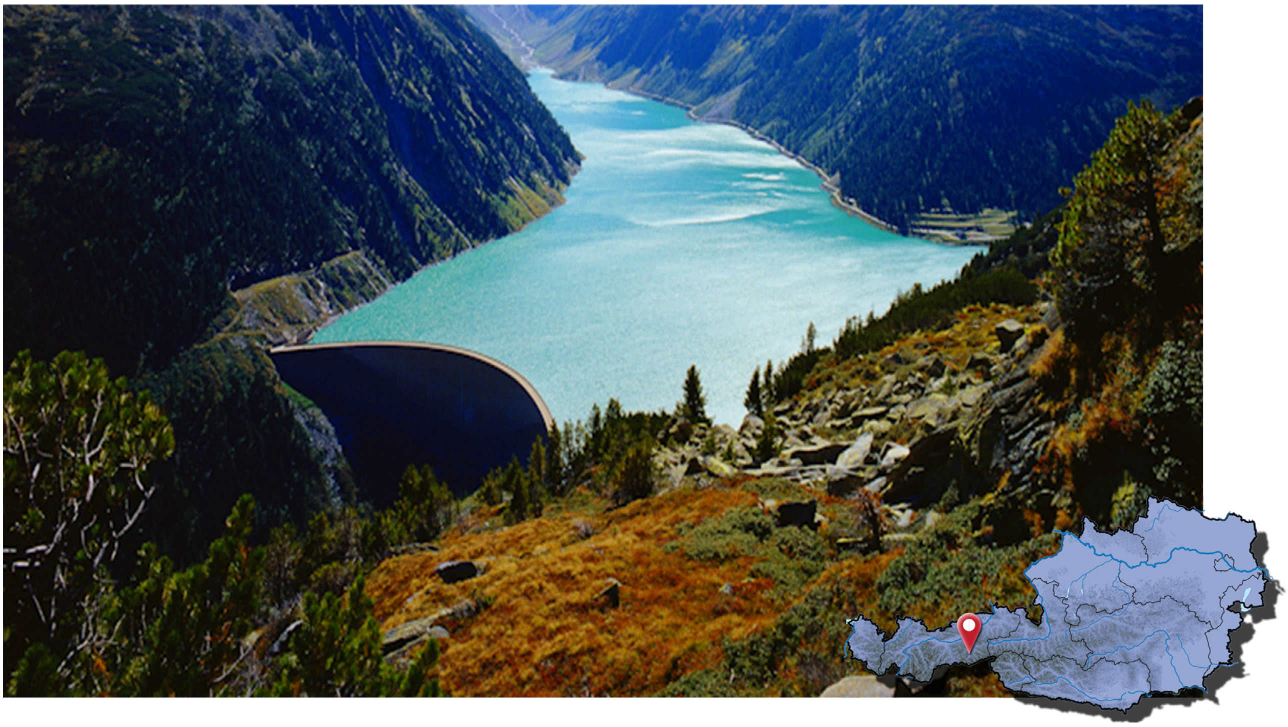
The PSH Häusling was added in 1974. The run-of-river plant Gunggl in 1987 was the last power plant to finish the Zemm-Ziller group.

The power plant group produces 1 250 GWh annually with a total installed capacity of 965.7 MW. The total pumping capacity of the pumped storage hydropower plant Roßhag and pumped storage hydropower plant Häusling are 600 MW, this hydropower plant make this group to one of the most powerful power plant groups in Austria. Since 1970, the storage plant Mayrhofen produces 670 GWh per year. It consists of the storage Stillup, a penstock and the power house Mayrhofen, which operates 6 machine units with horizontal shaft and a total installed capacity of 345 MW.

The core of the power plant group, the reservoir Stillup, has a maximum operation level at 1120 m.asl and a live storage of 6.6 million m³. It acts as a storage for the storage hydropower plant Mayrhofen and as well as for the pumped storage hydropower plants Roßhag and Häusling.



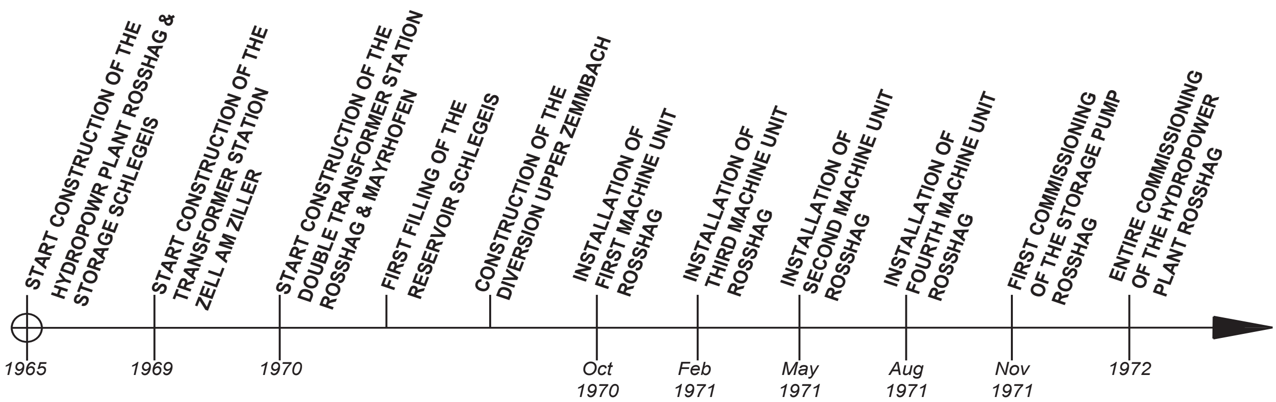
Hydropower scheme of Zemm-Ziller



ROSSHAG

PUMPED STORAGE HYDROPOWER

Commissioning	1972		Live Storage **Stillup**	6.8	[Mio. m³]
Machine type	Francis turbine with storage-pump		**Mean Gross head**	634	[m]
Headrace Surge Tank	two-chamber differential surge tank with vortex throttling		Installed capacity **Turbine**	230	[MW]
Discharge **Turbine**	52	[m³/s]	Installed capacity **Pump**	240	[MW]
Discharge **Pump**	36	[m³/s]	**Energy content**	197	[GWh]
Live Storage **Schlegeis**	126.5	[Mio. m³]	**Company**	Verbund	



Reservoir Schlegeis [3]

PLANT DESCRIPTION

The pumped storage hydropower plant Roßhag uses the water of the reservoir Schlegeis to produce energy. 313.2 GWh electrical energy has been produced in average annually since 1972.

The 131 m high double curved arch dam Schlegeis, with the 725 m long dam crest at 1782 m.asl and required almost 1 million m^3 volume of concrete.

The maximum water level of the storage is located at 1782 m.asl with a live storage of 126.5 million m^3. An elastic seal wall is used as sealing and approximately 700 measurement devices are installed to monitor the arch dam.

A pressure tunnel, a surge tank and a steel lined pressure shaft form the penstock, which is linked to the valve chamber Lichteck and connected through a distribution pipe to the power house Roßhag.

Four machine units with Francis turbines, motor generators, two stage single flow pumps and hydraulic converters are installed in the machine hall. A transmission line (220 kV) transports the energy to the switchyard Mayrhofen.

Further developments in turbine construction enable use of the maximum gross head at about 674 m with Francis turbines.

The pumps are installed at the required level of 1045.5 m.asl. This is close to the minimum operation level at the reservoir Stillup.

Pressure tunnels for the headrace system are used at high and low-pressure side. This is the reason for the four distribution pipelines used in the power house. Spherical valves are used for turbines and pumps at the high pressure side, while at the low pressure side they are just used for the pumps.

Turbines at the low pressure side use eccentric butterfly valves which open in case of high pressure.

RESERVOIR MANAGEMENT

For the pump storage itself, the water from the storage Stillup is available. Since the pump is installed, operating periods at the power plant Roßhag increased.

The full storage, without diversions make it possible to pump with two machine units (115 MW) around 100 hours at once and with four machine units (230 MW) around 50 hours.

The gross head varies between 560 m and 676 m, because of the water level conditions.

A software controls the individual procedures as well as the individual plant components. This technology enables into put on operation all machine units at the same time and connect the units parallel online from standstill within 2 minutes.

The capacity can adapt to the grid through the fast-acting regulation of the power output. Within 30 to 45 seconds the capacity can increase from zero to the maximum.

Several changes from part load to full load operation and reverse as well as changes between pump operation to turbine operation and reverse are possible. The system just need a maximum of three minutes from start of commissioning of the turbine until the start of the pumping process.

The load distributor is located in Kaprun, Salzburg. The main distributor is located in Vienna. Electric and hydraulic data such as water levels at the storage or the switch status of the plant are transmitted to the distributor Kaprun.

An electrical data processing system installed at the power plant Mayrhofen monitors the operation of the Zemmkraftwerke including the registration and treatment of the data. The hydropower plants Roßhag and Häusling are operated with hydraulic short circuit to control the energy input through the turbine during regular pump operation.

Reservoir Schlegeis in Winter [3]

Headrace tunnel Roßhag under construction [3]

POWER WATER CONDUIT

The headrace tunnel consists of the pressure tunnel, the surge tank Pitzenalpe and the valve chamber Lichteck. The pressure shaft consists of an inclined and a horizontal section and is situated after the valve chamber Lichteck followed by the distribution pipeline to the power house Roßhag.

INLET CONSTRUCTION AND VALVE CHAMBER SCHLEGEIS

The inlets for one of the two bottom outlets and the headrace system were combined. The position is located almost in the centre at the reservoir Schlegeis.

The valve chamber Schlegeis is located between the inlet construction and the surge tank Pitzenalpe, shortly after the dam.

Two oil pressure controlled gates at the valve chamber Schlegeis connect the reservoir and the headrace tunnel.

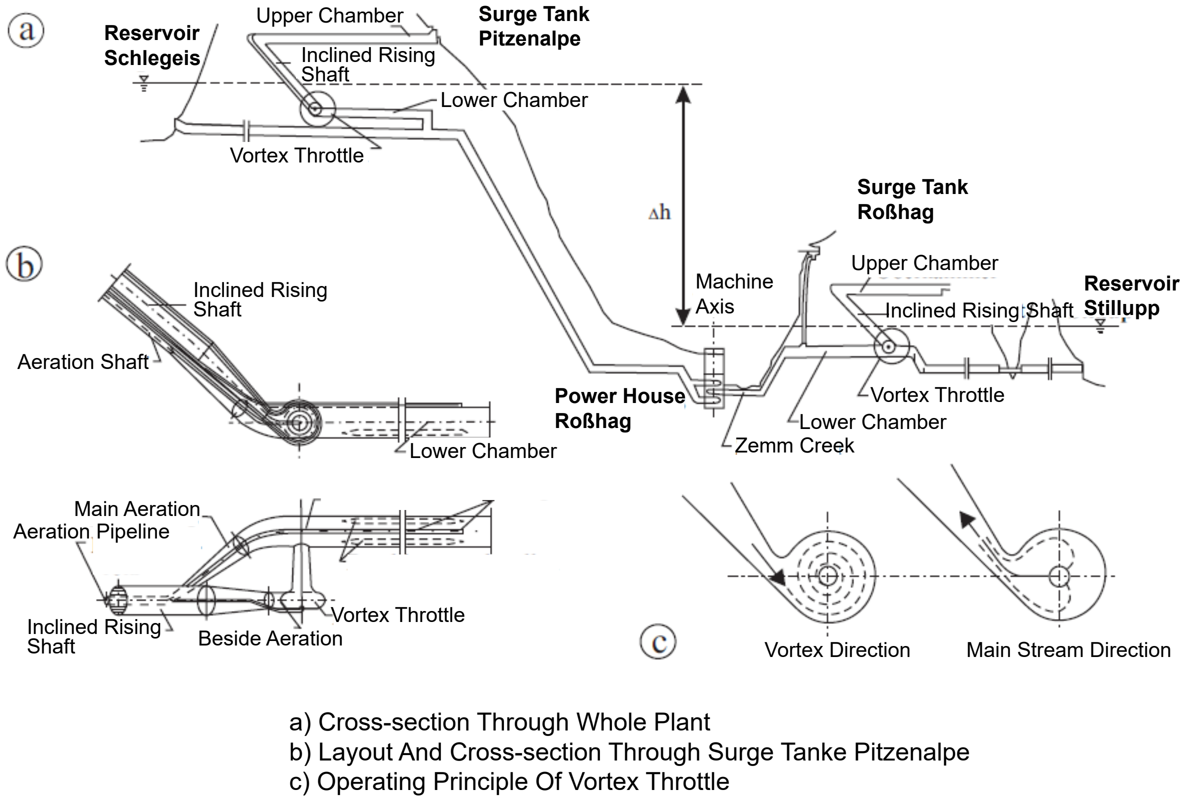
HEADRACE TUNNEL

The headrace tunnel leads from the inlet Schlegeis to the surge tank Pitzenalpe and has a length of 7773 m. Three streaming diversions are installed along the headrace tunnel.

The good rock mass conditions were found at areas with bulky rock (i.e. granite-gneiss) became clear from the geological record, expect for some succession and fault zones.

However, safety measures and problems emerged at areas with layered materials (i.e. slate gneiss). The inclination to a maximum of 8.5 ‰ ensured that the tunnel could be excavated from two sides. The tunnel has an internal diameter of 4 m and an excavated diameter of 4.6 m.

The gallery cross-sections based on an average flow rate from 4 to 4.5 m/s, including the streaming diversions. The calculated losses result an energy line gradient of maximally 2.7 ‰. The major static inner pressure is around 16.2 bar with a maximal flow of 52 m³/s. All headrace tunnel were excavated by drill and blast.



Tow chamber surge tanks with vortex throttles of Pitzenalpe and Roßhag [1]

The cleaning of the sole made in reverse gear alternating on one side and at the same time, a horizontal prior sole was concreted. The steeply layered material at the direction of the surge tank effected some appearances of relaxation similar to a occurred rock burst during excavation near the surge tank.

The roughness parameter by Strickler at least 83 $m^{1/3}/s$ was required. To ensure this, a smooth formwork was used and partially minor increased tunnel cross-section. The tightly lining thickness of 20 cm or 15 cm ensured through a major excavation. A telescope formwork made largely of aluminium was used to produce a full-round lining avoiding of longitudinal joints.

SURGE TANK PITZENALPE & ROSSHAG

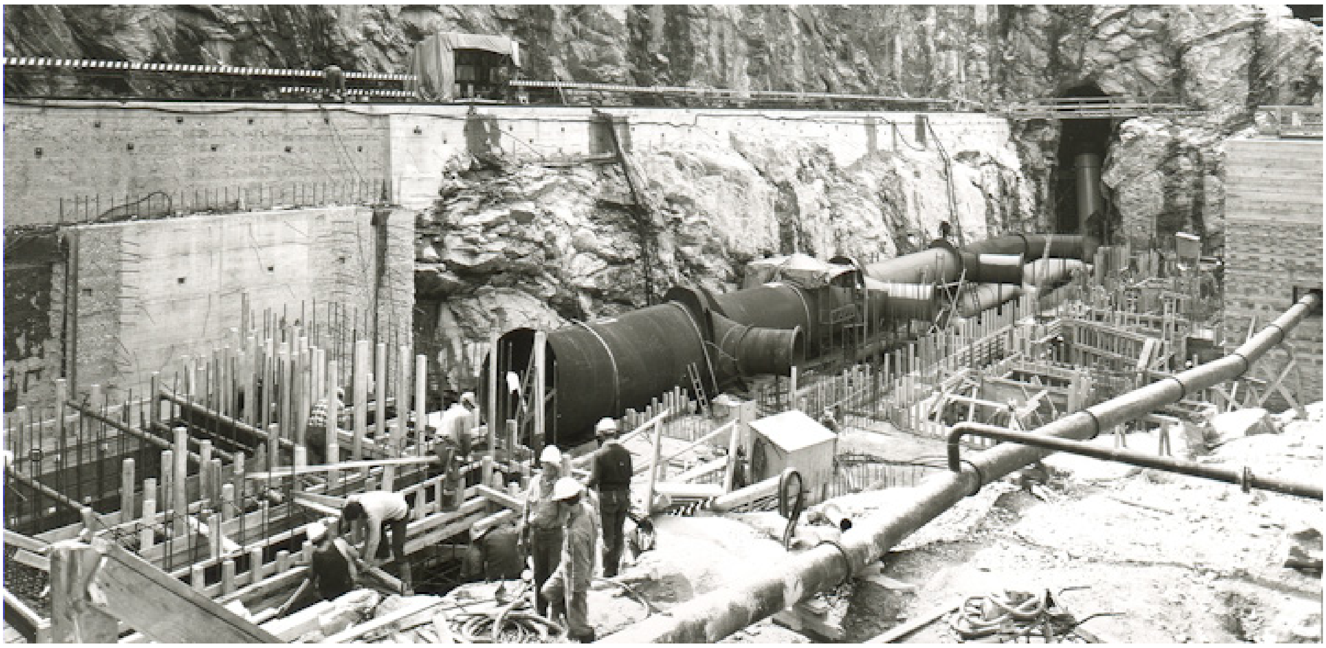
The surge tank Pitzenalpe is situated at the transition of the pressure tunnels to the pressure shaft. A two-chamber differential surge tank with vortex throttle is provided.

The throttle is located at the point of transition from the lower chamber to the inclined rising shaft. The aeration shaft from the lower chamber leads air directly to the upper chamber. The throttle only considers fixed devices, because of the susceptibility of movements. The vortex throttle consists of a torus, which has a higher resistance against down flow direction.

The surge tanks Pitzenalpe and Roßhag influence each other. The surge tank Roßhag designed as two-chamber surge tank with orifice and flushed lower chamber. The surge tanks have different natural oscillation periods.

The lower chamber of the surge tank Roßhag constructed as a part of the headrace tunnel to save chamber volume. The worst case is a short-term flow rate to the pumps with 32 m^3/s. The shaft function as aeration of the chamber with 385 m in length and an air piping is additionally installed. The orifice situated at the transition between lower chamber and inclined shaft.

This chamber has the function to discharge the water from the Zemmbach in case of low surge tank level. Laboratory tests at the TU of Vienna have prove the stability of the entire system.



Construction site at the power house Roßhag [3]

The horizontal cross-sections of the shafts fulfil the extended Thoma stability criteria. The TU Graz calculated the stability of the entire system, graphical according to Schocklitsch and with a program controlled electronic calculator.

The chambers of the surge tank Roßhag have a diameter of 6 m and the others of the surge tank Pitzenalpe have a diameter of 5.1 m. The upper chambers are lined with shotcrete. The throttle is steel lined because of high strain results of energy dissipation. The aeration pipes are anchored and concreted at the soles of the inclined shafts.

PRESSURE SHAFT

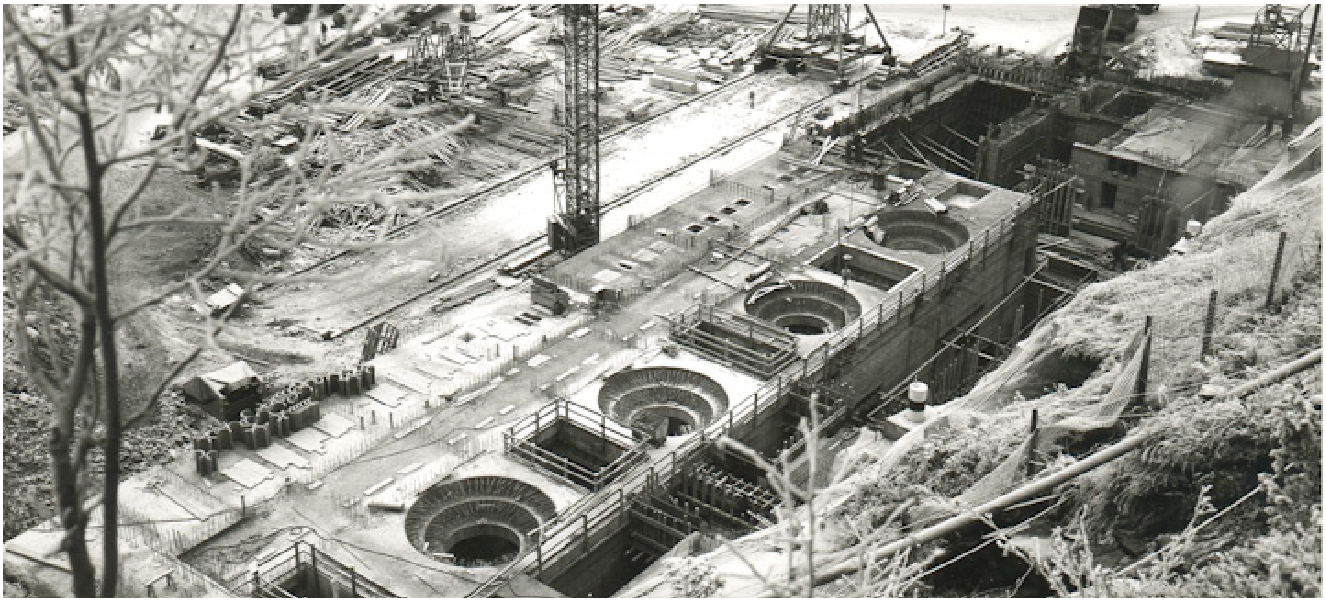
The 1267 m long pressure shaft consists of a inclined and a horizontal section. It is located at the orographically left valley flank of the Zemmtal above Roßhag.

The horizontal section built in stable gneiss as well as the inclined section but there contained some gaps.

The 897 m long and 33° inclined section of the pressure shaft has an excavated diameter between 3.3 m to 3.5 m, an internal diameter between 2.9 m to 3.1 m.

Whereby the horizontal section with 370 m in length has an internal diameter of 2.9 m and is inclined by 2 ‰. The horizontal section has an overburden from 20 m to 160 m.

The average gross head is about 629.7 m and the pressure shaft is designed for a discharge of 50 m^3/s.



Construction site at the power house Roßhag [3]

POWER HOUSE

The power house Roßhag is situated at an area exposed to avalanches and therefore the entire construction was designed against heavy import. The components can withstand a pressure of about 20 t/m² to 50 t/m². The power house has a total length of 82 m, the width at the footing base (1041.4 m.asl) are 12.8 m and the height of the machine hall is 27.5 m at 1062 m. From the total height of 40 m, belong 23 m with 34000 m³ room area to the civil engineering part and 17 m with 33000 m³ room area to the building construction part.

The pipes at the high-pressure side have a diameter from 1 m to 2.9 m and the pipes at the low - pressure side for the pumps and the turbines have a diameter from 1.5 m to 3.3 m.

The 19.3 m high valve chamber is located between the machine units and the distribution pipelines. All gates for the pump and the turbine are installed at this chamber.

The building construction generally consists of the entrance hall, the machine hall and the transformer porch. The machine hall with the dimensions 69 m/11.5 m/15 m accommodates the four machine generators of the machine units.

MACHINE UNIT

The four machine units are situated in the machine hall of the power house Roßhag. Each machine unit, equipped for the pump operation, consists of a Francis turbine applied from Andritz Hydro, a motor generator by the company Elin from 1970, a two stage pump by Voith from 1970 as well and a hydraulic torque converter.

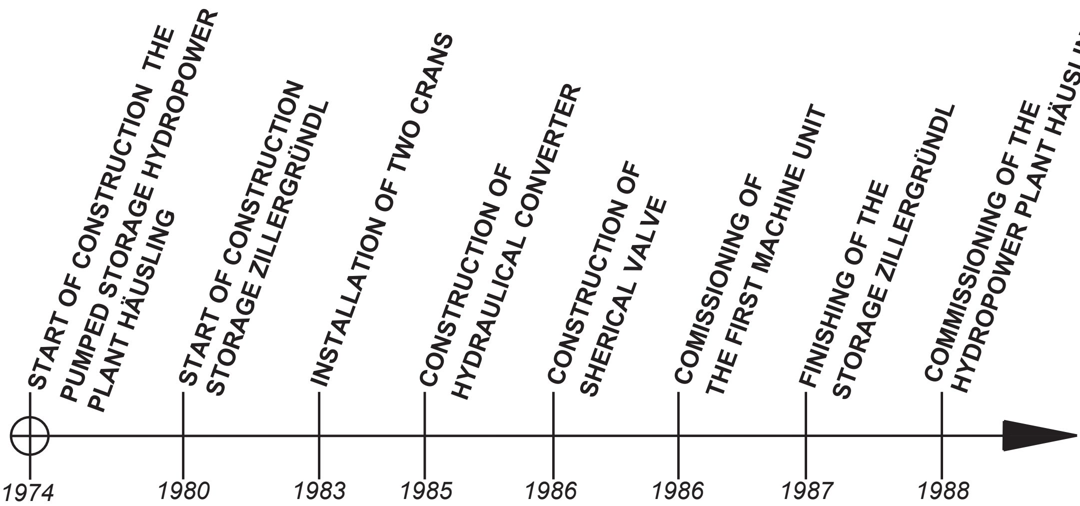
The normal output amount 57.5 MW per turbine, 65 MVA per motor generator as well as 60 MW per storage pump. Another machine unit consisting of a horizontal single-jet Pelton turbine with an normal output of 1 MW and an alternator with 1.25 MVA is installed to cover the own requirements. The machine units including the unit for the own requirements produce a normal output of 231 MW.

The energy is initially transported by the indoor SF6 gas insulated switchyard through a underground 220 kV oil filled cable into a 240 m long tunnel and a 220 kV overhead line transports the energy to the Mayerhofen switchyard.

HÄUSLING

PUMPED STORAGE HYDROPOWER

Commissioning	1988		Live Storage **Stillup**	6.8	[Mio. m³]
Machine type	Francis turbine with storage pump		**Mean Gross head**	634	[m]
Headrace Surge Tank	two-chamber differential surge tank with vortex throttling		Installed capacity **Turbine**	360	[MW]
Discharge **Turbine**	65	[m³/s]	Installed capacity **Pump**	360	[MW]
Discharge **Pump**	43	[m³/s]	**Energy content**	244	[GWh]
Live Storage **Zillergründl**	86.7	[Mio. m³]	**Company**	Verbund	



Reservoir Zillergründl [5]

Zillergründl dam [5]

PLANT DESCRIPTION

The pumped storage hydropower plant Häusling uses the water of the storage Zillergründl. Since 1987, 180 GWh electrical energy has been produced annually. The water level of the storage located at 1850 m.asl with 86.7 million m^3 live storage.

The 186 m high double-curved arch dam Schlegeis has a concrete floor in front of the dam at the water site and is connected to the dam with a 100 m deep elastic sealing element.

Around 1300 measurement devices are installed to monitor the arch dam and are primary at the inspection galleries, the bottom gate and the vertical shafts.

The tunnel system, which includes the pressure tunnel, the pressure shaft and the stream diversion. The tunnel has a total length of around 14 km. The pressure shaft after the valve chamber Ofenwald consists of a thin steel lined and slightly inclined shaft followed by a horizontal section below.

The highest part of the power house Häusling is almost 64 m high. The shaft facility has a depth of around 40 m by a cylindrical section with a diameter of 32.8 m.

Two machine units with Francis turbine, motor generator, double stage single flow pump and hydraulic converter are installed in the power house. A transmission line transports the energy to the outdoor substation Mayrhofen.

View of the Zillergründl reservoir [4]

POWER WATER CONDUIT

The headrace tunnel consists of the inlet/outlet building Zillergründl, the inlet tunnel, the valve chamber Zillergründl, the pressure tunnel, the headrace surge tank Ofenwald, the valve chamber Ofenwald and the pressure shaft.

The headrace system after the power house Häusling on the low pressure side consists of the tunnel crossing the Zill river, the valve chamber Häusling, the surge tank Häusling and the Ziller diversion tunnel which leads to the storage Stillup.

The headrace penstock system and the water supplies for the streams have a length of about 14 km.

INLET/OUTLET ZILLERGRÜNDL & VALVE CHAMBER ZILLERGRÜNDL

The inlet building of headrace tunnel is situated at the orographically right side at the storage Zillergründl.

The inlet consists of a 225 m long inlet tunnel and a following throttle valve with a diameter of 3.7 m. The inlet tunnel was excavated by drill and blast, the conventional tunneling method.

PUMP STATION KLAMMBICHL

The water from the Hundskehl and Sunder creek could not be catched above the maximum operation level of the storage Zillergründl. Therefore, the two pumps installed in the pump station Klammbichl pumps the run-off water into the storage when the water level of the reservoir rises above 1790 m.asl.

The pumping station command two horizontal and semi-axial pumps. The pumps have a installed capacity of 4 MW with a delivery head of 66 m as well as a flow rate of 3.3 m³/s.

HEADRACE TUNNEL

The 7.4 km long headrace tunnel is concrete lined, has an excavated diameter of 4.7 m and an internal diameter of 4.2 m. The surge tank and the valve chamber is followed by the 140 m long steel lined horizontal section with an inner diameter of 3.7 m and an excavated diameter of 4.2 m.

The headrace tunnel was excavated by drill and blast without specific geological difficulties. The average excavation performance was around 27.7 m each working day. The section after the first 1885 m of the inlet tunnel was excavated with a Jarva tunnel boring machine.

View power plant Häusling with reservoir Zillergründl [5]

SURGE TANK & VALVE CHAMBER OFENWALD

The surge tank is constructed as a two chamber surge tank with horizontal shaft and a vortex throttle between horizontal shaft and lower chamber. The valve chamber is equipped with a throttle valve with a diameter of 3.7 m. The surge tank was conventional excavated and concrete lined.

PRESSURE SHAFT

The pressure shaft has a length of 835 m, it inclined by 45° and has an inner diameter of 3.7 m diameter. It subsequent to a bend. A Jarva full thickness cutting machine (D = 4.2 m) was used to excavate.

The excavation started in September 1976 with an TBM and had to be stopped in March 1980 at the upper end of the pressure shaft. The reason for this was that, the TBM had penetrated a strong weakness zone. Continued with the conventional procedure together with the excavation of the surge tank and the valve chamber. The inclined part of the pressure shaft is excavated with a Robbins tunnel boring machine.

A conventional lining is used in consideration of mountain effects. The shaft is steel lined and the annular gap between outbreak embrasure and the lining was grouted with channel concrete.

Originally, three variants for the shaft lining were discussed:

- a conventional heavy lining,
- thin-walled lining with inner ring made of concrete,
- and another option with a sealing by foil.

After a investigation of technical and economic terms, the decision was made to use at one section a 360 m long conventional lining, a 900 m long thin-walled lining at another section and in the area of the surge tank a 640 m concrete lining with a sealing by foil.

Machine unit Häusling [4]

Power house Häusling [7]

POWER HOUSE

The power house Häusling is a further development of the existing power house Roßhag. The longitudinal side oft the power house Häusling is dug into the rock thus far, so the machine shaft and hall are totally founded on rock, which is cured in a similar way at the power house Roßhag. Both power houses have a greened flat roof.

It is difficult to get an idea of just how big the power house is by looking at the outside of the building. One of the most important tasks for the architect Konrad Aufhammer was the inclusion within the landscape. The reduction of the visible building mass and the production of a as small as possible silhouette was an very important issue.

The biggest height of the building is 64 m and is not visible from the outside. The shaft consists of a detached steel concrete cylindrical shaft with an outer diameter of 32.8 m, a depth of around 40 m and is totally founded on rock mass. The building hand the slope situated behind it have no direct anchoring. Hydraulic cushions on the hill side of the ground and the first floor prevent the transmission of stresses that where known from experiences of the power house Roßhag.

The workshop at the power house consists of two connected rooms. Two coupling cranes by Liebherr from 1983 and the other were installed on the third floor below ground at the rotary valve hall.

Transformer Häusling [4]

MACHINE UNIT

Each of the two machine units contains of a Francis Turbines with vertical shaft which have an total height of 40 m applied form the Andritz Hydro, a two-stage single flow pump by J. M. Voit from 1986 and a hydraulic converter. The machine units at the power house Häusling have a installed capacity of 360 MW.

Also part of the unit are the new dewatering pumps by the company Ernst Vogel. The development starts in 1970 and the first machine unit got in operation in 1988.

The suction pipes at the power house were installed overhead in order to ensure a advantageously management of the low-pressure distribution pipeline. The torque converter is installed between the pump and the turbine to get a quick switching time.

The four storage pumps which are constructed as radial double flow pumps, with a normal capacity of each 180 MW and an flow of 21.5 m^3/s have a start-up converter with gear coupling. The two motor generators of Elin supply in normal operation 200 MVA, a need in pump operation a power of 180 MW and an operation voltage of 20 kV.

A 220 kV, SF6 gas insulated switching module and a 220 kV overhead line transports the power to the Mayerhofen switchyard. All power plants of the hydropower plants Zemm-Ziller as well as the power plant Häusling are controlled by the central control room at Mayrhofen.

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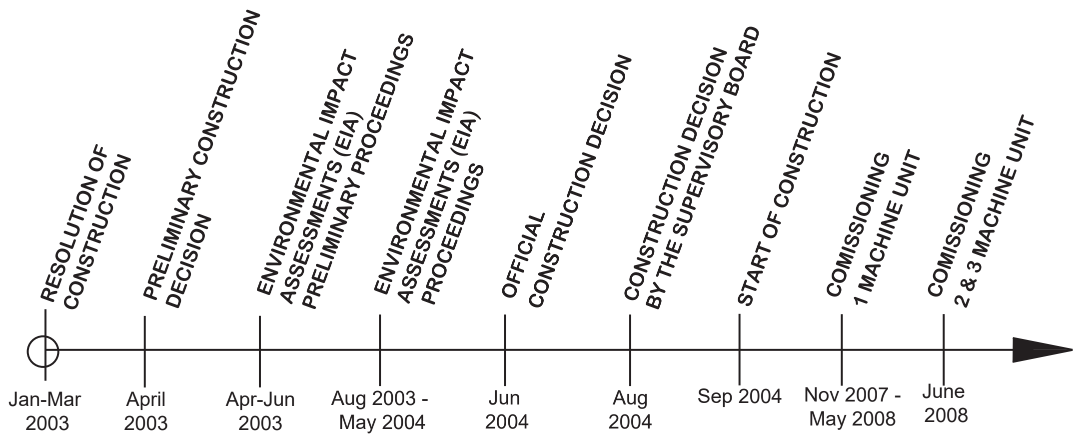
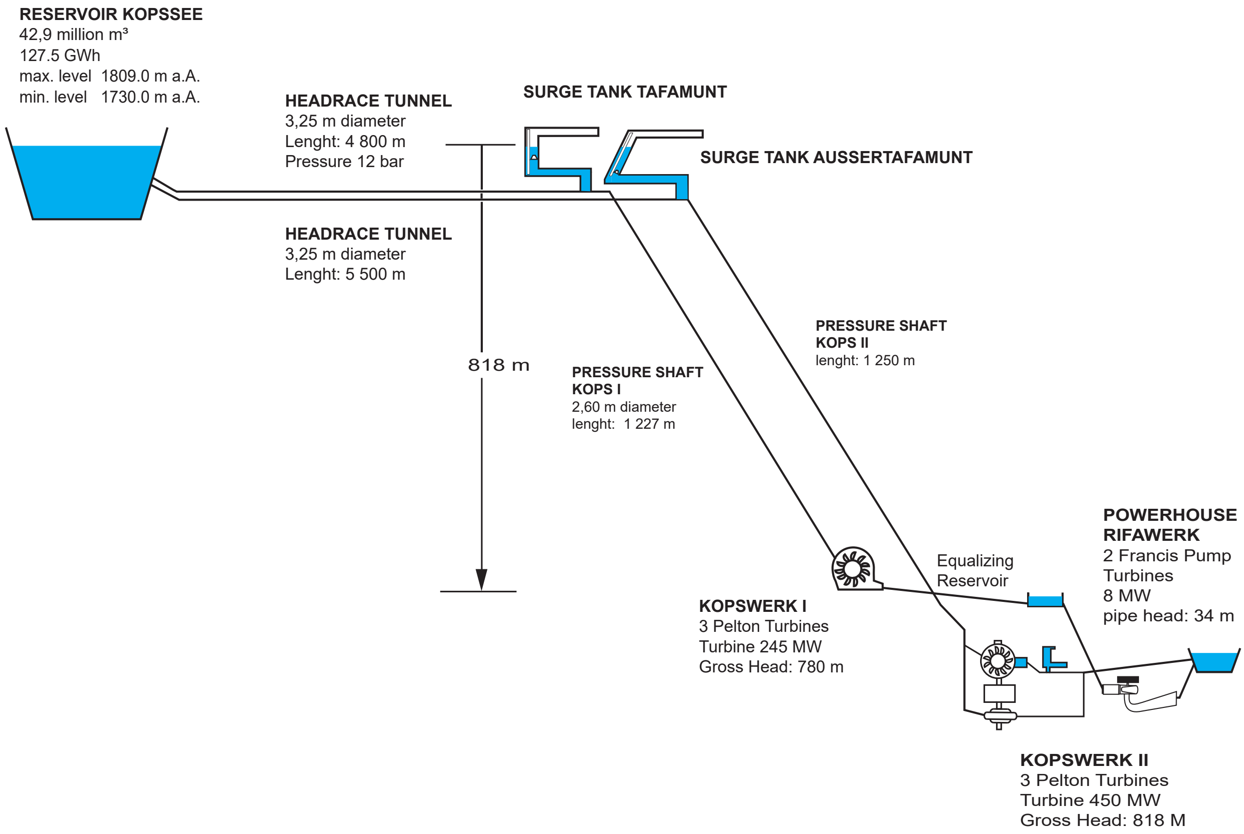
Date: 2016-12-22

KOPSWERK II

PUMPED STORAGE HYDROPOWER PLANT

Commissioning	2008		Live Storage **Rifa**	1.27	[Mio. m³]
Machine type	Vertical ternary Pelton-turbine Storage Pump		**Mean Gross head**	818	[m]
Headrace Surge Tank	Asymmetric trottled Two-chamber system		Installed capacity **Turbine**	450	[MW]
Discharge **Turbine**	80	[m³/s]	Installed capacity **Pump**	450	[MW]
Discharge **Pump**	58	[m³/s]	**Energy content Upper Stage**	67	[GWh]
Live Storage **Kopssee**	42.9	[Mio. m³]	**Company**	Vorarlberger Illwerke	





Hydropower scheme of Kopswerk I and II

PLANT DESCRIPTION

The pumped storage hydropower plant Kopswerk II is owned by the Vorarlberger Illwerke and located in Gaschurn in the Montafon valley, in the Austrian province of Vorarlberg. It was constructed between 2004 and 2008 parallel to the existing plant Kopswerk I constructed in 1970.

The pumped storage system uses the water from the mountain group Silvretta and has a total installed capacity of around 695 MW. The plant got in operation in 2008 with three machine units. The storage Kops at 1800 m.asl and the Rifa reservoir at 1000 m.asl provide storages for the pumped storage operation.

The Illwerke own and operate the hydropower plant groups Upper Ill and Lünersee Rodund. The Upper Ill group consists of the hydropower plant Vermunt (157 MW), Obervermunt I (30 MW), Rifawerk (7 MW), Kopswerk I (245 MW) and Kopswerk II (450 MW).

The Lünersee Rodund group consists of he hydropower plant Lünerseewerk (280 MW), Rodund I (198 MW), Rodund II (295 MW), Latschauwerk (9 MW) and Walgauwerk (86 MW). Actually, the hydropower plants Rellswerk (12 MW) is nearly completed to get in operation and Obervermunt II (360 MW) is expected to be finished by the end of 2018.

The amount of peak and control energy is higher than Ill - Kopswerk I, Vermunt and Obervermunt together and the input power at pumping operation is almost higher than Lünerseewerk, Rodund I and II together.

Kopswerk II was planned and constructed as a cavern power plant thus just the access road and the switchgear are visible from the outside. The headrace tunnel leads the water from the storage Kops to the Rifa reservoir. The storage Kops is already used by Kopswerk I built in 1970.

The reservoir Kops is 500 m away as the crow flies from the storage Rifa and the gross head of the power plant amounts to around 818 m between the full water level of the reservoir Kops at 1811 m. asl and the drawdown level in the Rifa basin at about 1006 m. asl.

The reservoir Kops has a capacity of 42.9 million m³ as the upper basin and the Rifa basin has a usable capacity of 1.27 million m³ as the lower basin. The discharge in turbine operation is Q_T = 80 m³/s and in pumping operation Q_P = 58 m³/s.

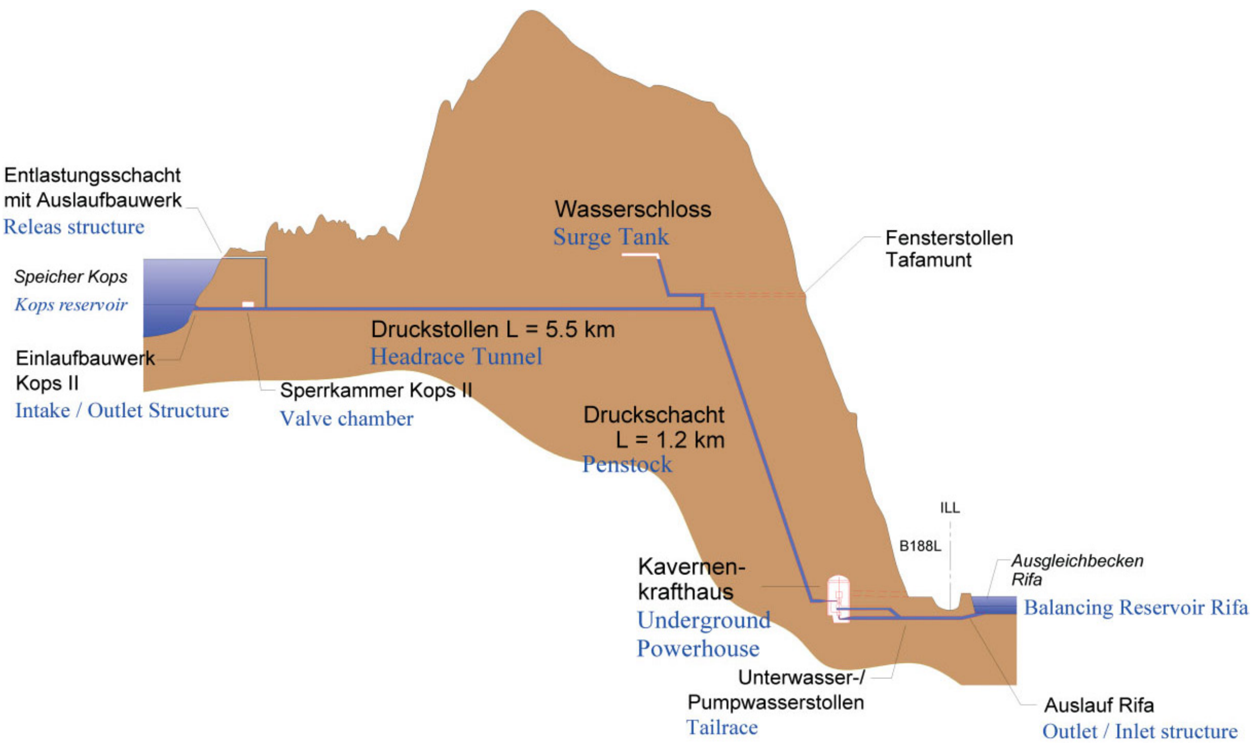
The work for the around 360 million € project was split into three contracts for design and construction purposes.

The first contract section was the headrace tunnel Versal II from the storage Kops to the beginning of the pressure shaft at Maisäß Tafamunt and the intake building at the storage Kops. The water content of the storage Kops was discharged in winter 2005 / 2006.

The second contract consisted of the construction of the pressure shaft including the surge tank Tafamunt.

The pressure shaft leads from Tafamunt at around 1600 m to the machine cavern with a height difference of approximately 700 m and for the excavation, a tunnel boring machine was used. The machine cavern including the tailrace tunnel and the discharge were built within the third contract part.

Two caverns were built into the mountain, one as machine cavern and the other as transformer cavern. To be installed into the machine cavern a machine unit with Pelton turbine, motor generator, separation of turbine and pump through hydraulic converter and a pump with horizontal shaft was chosen to secure a hundred per cent controllability.



Longitudinal section of Kopswerk II [12]

Reservoir Kopssee [1]

RESERVOIR MANAGEMENT

Deregulation of electricity marketin Europe in the nineties exposed existing monopolies to the free market. Electricity customers can freely choose their energy supply.

Peak and regulation energy is necessary to respond rapidly to market fluctuations and reassign its capacities in a flexible manner, which also stabilizes the power supply. The storage and pumping hydropower plant by the Illwerke provides this high quality peak and control energy for the power market.

The Kopswerk II in Vorarlberg set new standards. It utilizes ternary machine units with pump and separated turbine instead of a pump turbine. The power plant can feed up to 450 MW of energy into the grid as peak load, or absorb 450 MW of surplus power from the grid.

The machine units are constructed to operate by utilizing short hydraulic circuits, which means that the storage pump and the turbine can operate simultaneously. This is the key technology to allow full control for pump operation and thus high flexible surplus power regulation.

The motor generator and the separate turbine and pump set of the Kopswerk II pumped storage plant in addition to the use of a hydraulic torque convertor make it possible to switch between turbine and pump operation in a matter of about 30 s.

The combination of Pelton turbine and hydraulic converter via hydraulic short circuit makes the power plant highly adjustable. The part load capacity of the Pelton turbine amounts from 15 % to 100 % as well as 5 % of the total capacity at turbine operation and 95 % adjustable at pumping operation.

Rifa reservoir [4]

Extension works at the Rifa reservoir [3]

POWER WATER CONDUIT

The headrace tunnel consists of the inlet / outlet building at the reservoir Kops, a valve chamber, a release structure, a 1.1 km long headrace tunnel, the surge tank Außertafamunt and the pressure shaft.

The tailrace system downstream the underground power house on the low pressure side consists of a free surface shaft surge tank, as well as an air cushion surge tank in the tailrace channel of the Pelton turbine, a tailrace tunnel, and the inlet / outlet building which leads to the storage Rifa. The pressure tunnel, the pressure shaft and the water supplies for the streams have a total length of about 14 km.

BOTTOM OUTLET/INLET BUILDING KOPSWERK II

Water for the pumped hydropower station is drawn from the Kops reservoir through a new inlet building. The inlet / outlet building Kops II is around 105 m to the east of the inlet building Kopswerk I. The inlet is located at 1723 m.asl, 7 m below the design minimum operation level of 1730 m.asl.

After an inclined bend in the transition to the rock joints, the 162 m long intake tunnel with a drop of 33.4 % is connected, which passes through a section with diameters from 4.3 m to 4.6 m into the upstream anchor pipe of the valve chamber of Kopswerk II.

A connection between the Kops reservoir and the valve chamber is provided through the intake tunnel after the inlet structure. Butterfly valves in the valve chamber shut off the storage to the headrace tunnel. Thus, the intake tunnel is constantly under pressure.

The valve chamber is exposed to atmospheric pressure and the system has to be able to withstand the full pressure. The excavation of the intake tunnel was performed by drilling and blasting. The tunnel has support consisting of reinforced shotcrete and systematic rock bolting of 2 m × 2 m and with a bolt length of 4 m.

The tunnel has a circular unreinforced in-situ concrete lining with a thickness of 25 cm. A systematic waterproofing grouting was originally not provided along the intake tunnel. However, the first test filling showed that the loosening caused by blasting around the tunnel had created extensive water routes and bypasses.

Systematically grouting was subsequently carried out along more than half of the intake tunnel in order to seal these passages.

Construction site at the headrace tunnel [12]

Bottom of the rising shaft [8]

VALVE CHAMBER KOPSWERK II

An operation and maintenance regulation valve with 4.3 m diameter was installed at the valve chamber and can be reached through the Oberwald access tunnel.

To shut off the flow from the reservoir, butterfly valves are integrated at the valve chamber. The valve system has to be able to resist the full reservoir water pressure, which is generated through the intake tunnel. In case that the regulating gates are closed, this causes a maximum cover compression force of about 26000 kN. Also in the case of closing moments, the forces have to be transferred mainly through the foundations into the rock mass and also have to be partially consisted by the upstream anchor pipe on account of its high stiffness.

RELEASE STRUCTURE

The release structure is a device for the relief of excess pressure in pumping operation in the headrace tunnel Versal II. This system consists of a 145 m high shaft with a diameter of 3 m, channel off shortly below the valve chamber, a horizontal relief tunnel approximately 87 m long with a height of 3.1 m and a discharge structure joined to it, which appears above the highest water level of the storage Kops.

HEADRACE TUNNEL

The pressure tunnel Versal II is located in the central zone of the Silvretta crystalline and this metamorphic rock series is characterized by the Alpine tectonics, and thus by folding and the formation of fault and fracture zones.

The components of the headrace system including the pressure tunnel are exposed to high internal pressure fluctuations within a very short time due to the pumped storage peak flow operation of Kopswerk II.

The mountain water table can reach a peak of 450 m (45 bar), which could hardly be consisted with an economic lining alone. Therefore, a design concept is needed to include the surrounding rock mass into the structural system as far as possible, both with regard to rock pressure and formation water pressure.

The pressure tunnel Versal II leads from the valve chamber to the vertical connection of the surge tank before the pressure shaft. The tunnel was excavated through fault zones with overburden of up to 720 m.

The system has to resist the resulting fluctuations of internal pressure according to a head of up to 150 m within 20 s.

The Robbins TBM at Kopswerk II [5]

The section before the diversion Oberwald access entry is conventionally driven with a length of approximately 66 m, an inner diameter of 4.9 m, and a gradient of –0.52 % and has an in-situ concrete lining.

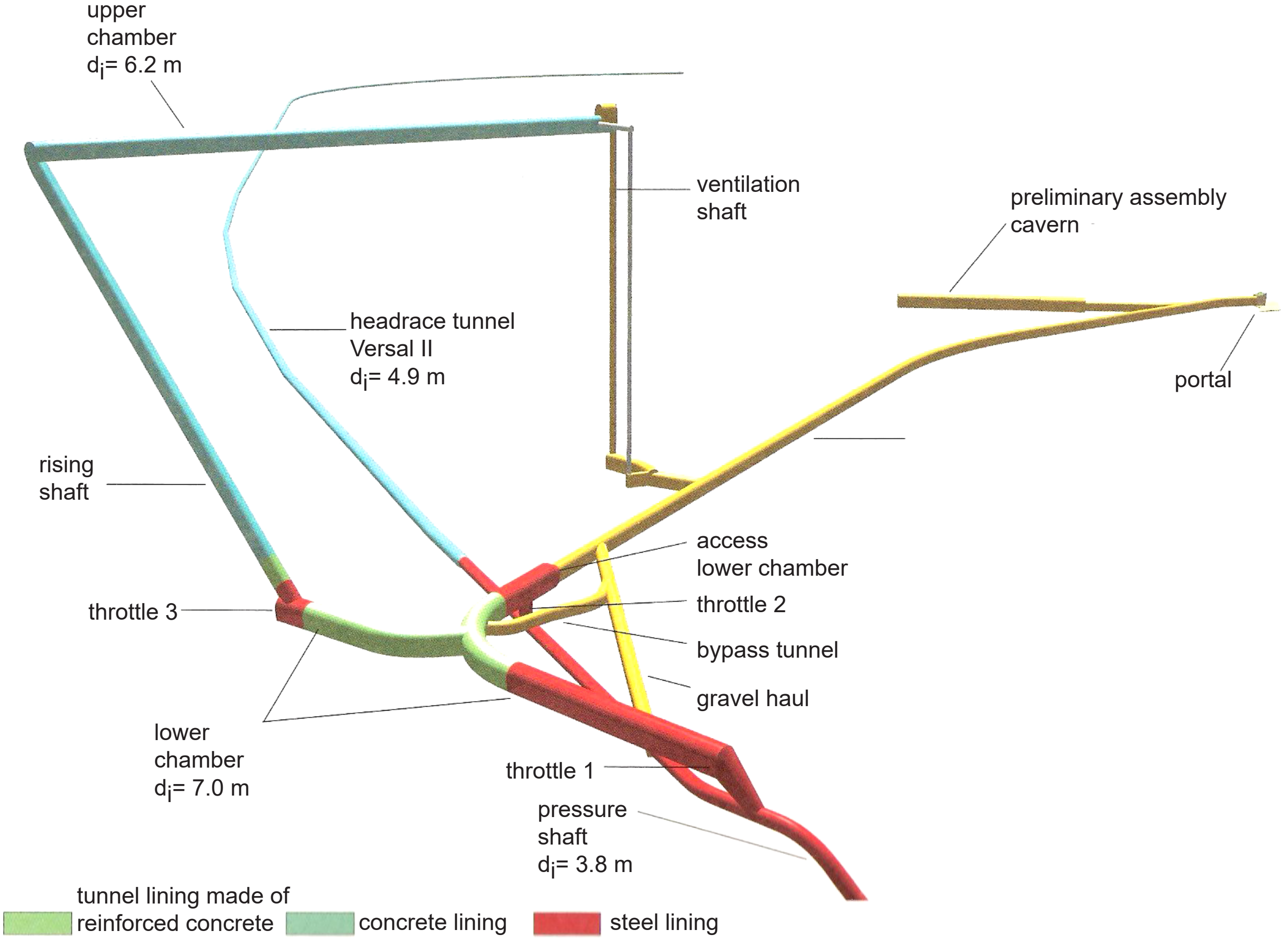
The part at the diversion Oberwald access entry is conventionally excavated, with a length of approximately 29 m, an inner diameter of 4.9 m, a gradient of 0.28 %, with in-situ concrete lining and a concrete plug with drain to close the access entry.

The tunnel boring machine access tunnel is excavated by blasting with a length of approximately 160 m, an inner diameter of 4.9 m, a gradient of 0.28 % and as well in-situ concrete lined.

The approximately 4.78 km long Versal II pressure tunnel with an excavated diameter of 5.54 m, an inner diameter of 4.9 m and a gradient of 0.37 % is mechanically bored.

A excavation by drilling from the area of the Außertafamunt surge tank and a length of 291 m with an inner diameter of 3.8 m to 4.9 m, a gradient of 0.37 % and in-situ concrete lining has the section from the end of the full segment lining to the steel liner. The transition and curved section has an in-situ concrete lining and an steel lining with concrete backfill at the surge tank.

Construction site of the headrace tunnel Kopswerk II [5]



Surge tank Außertafamunt [12]

SURGE TANK AUSSERTAFAMUNT

The surge tank is situated in Tafamunt and consists of two chambers including a rising shaft between the chambers as well as an aeration shaft, which leads to the surface via the access tunnel.

The lower chamber with a diameter of 7 m has a length of around 270 m and the upper chamber with a diameter of 6.1 m has a length of 240 m. The rising shaft in between has a diameter of 5.1 m, a length of 192 m and is longitudinally inclined with 49°.

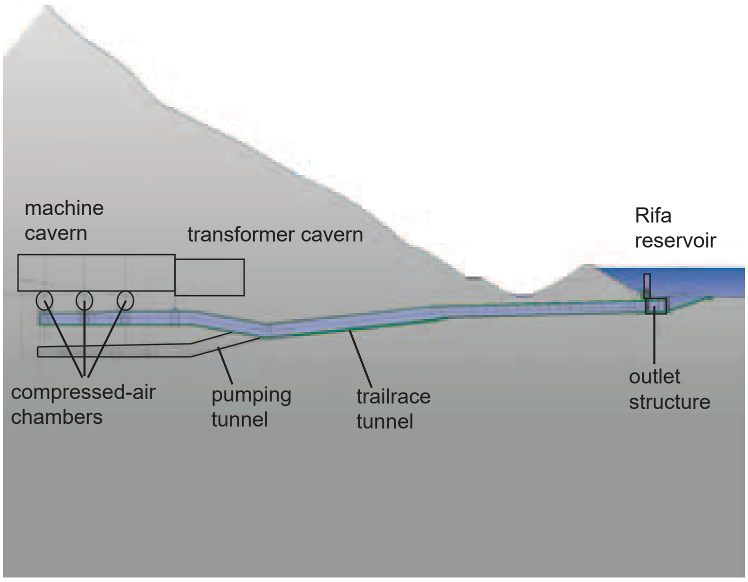
In addition, a differential throttle is situated at the bottom of the inclined rising shaft. The access tunnel appears as support to build maintenance and monitor the surge tank.

PRESSURE SHAFT

The shaft covers a height of 700 meters and has a total length of around 1.1 km. A TBM was used to excavate the shaft from Rifa to Außertafamunt. The pressure shaft consists of a horizontal and an inclined section.

The inclined section has a length of 1135 m, is declined with 38.7° and has an inner diameter of 3.8 m.

The connection between the pressure shaft and the powerhouse is created through distribution pipes, which have a diameter of 2.2 m with a following spherical valve of an inner diameter of 1.5 m.



Longitudinal section of the tailrace tunnel and the machine cavern [12]

Laboratory test of the tailrace channel system at TU Graz [M 1:22.5]

TAILRACE TUNNEL

The tailrace tunnel crosses a main road and the river Ill. The tailrace tunnel consists essentially of the intake and discharge in the Rifa reservoir, the 267 m long underwater tunnel, the underwater surge chamber with a 31 m high riser shaft (12 m diameter) and a 47 m long lower chamber and three compressed air chambers, which are connected to the underwater tailrace through a 77 m long connecting tunnel.

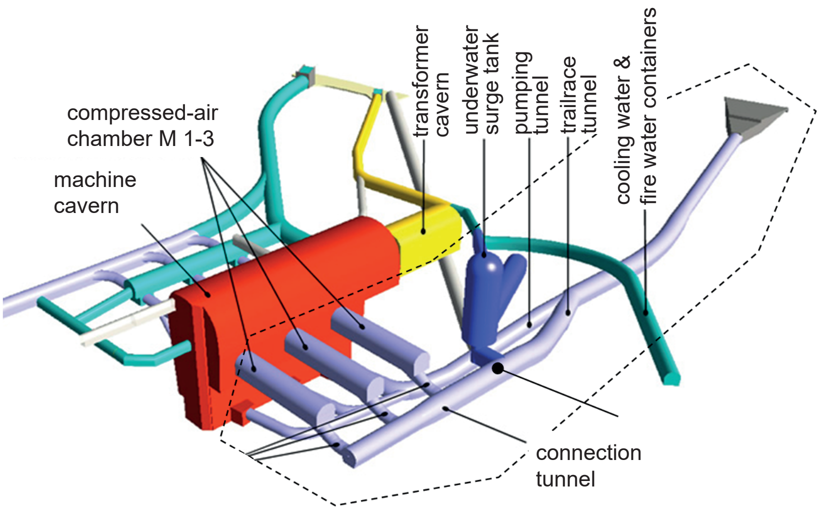
A challenge was the construction of the intake/ discharge structure in the Rifa reservoir. Due to the extreme cold and long winter. The deadline for filling of the Rifa reservoir was at the beginning of June. The work was partially done in day and night shifts.

UNDERWATER SURGE TANK

Another pressurized air surge tank was provided for the system, in the Pelton turbine tailrace channel.

The construction has a 31 m high rising shaft with an diameter of 12 m, a lower chamber which is 47 m long and three pressurized air chambers. Each of the three pressurized air chambers is 45 m and they are connected through the 77 m long connecting tunnel (figure below) to the tailrace tunnel.

The advantage is to place the tunnel axis of the Pelton turbine well below the capacity level of the lower reservoir.



Tailrace channel system [10]

MACHINE CAVERN

The powerhouse cavern is excavated 150 m inside the mountain and is the main component of the power plant. The machine sets are housed inside the powerhouse, while the transformer cavern houses the transformers.

The tailrace discharges the water in normal operation as well as the water intake during pumping operation.

The cavern presently belongs to the largest rock excavation works in the entire world. In order to be able to house the machine sets, each in total 38 m high, the cavern is 90 m long, 30.5 m wide and 60.5 m high, which causes an excavated volume of about 113000 m^3.

However, the transformer cavern is 35 m long, 16 m wide and 19 m high, with an excavated volume of about 10000 m^3.

Two concrete pumping masts were used. The masts should be arranged in such a way that all parts of the machine cavern could be reached without problems.

A mixing plant for assurance of fully independent and flexible working was set up on site.

Finally, pumped concrete was used and in addition, the beginning of concreting in the machine cavern was as well the beginning of the setup of the steelwork, which limited the availability of construction cranes.

The fitting out of the machine cavern consisted of up to 445 single components and was done in seven levels.

Three transformers are connected through power rails with the generator. The 220-kV-cable leads to the indoor switching station with SF6 technology beside the switchgear station Rifa.

Construction site of Kopswerk II cavern [2]

MACHINE UNIT

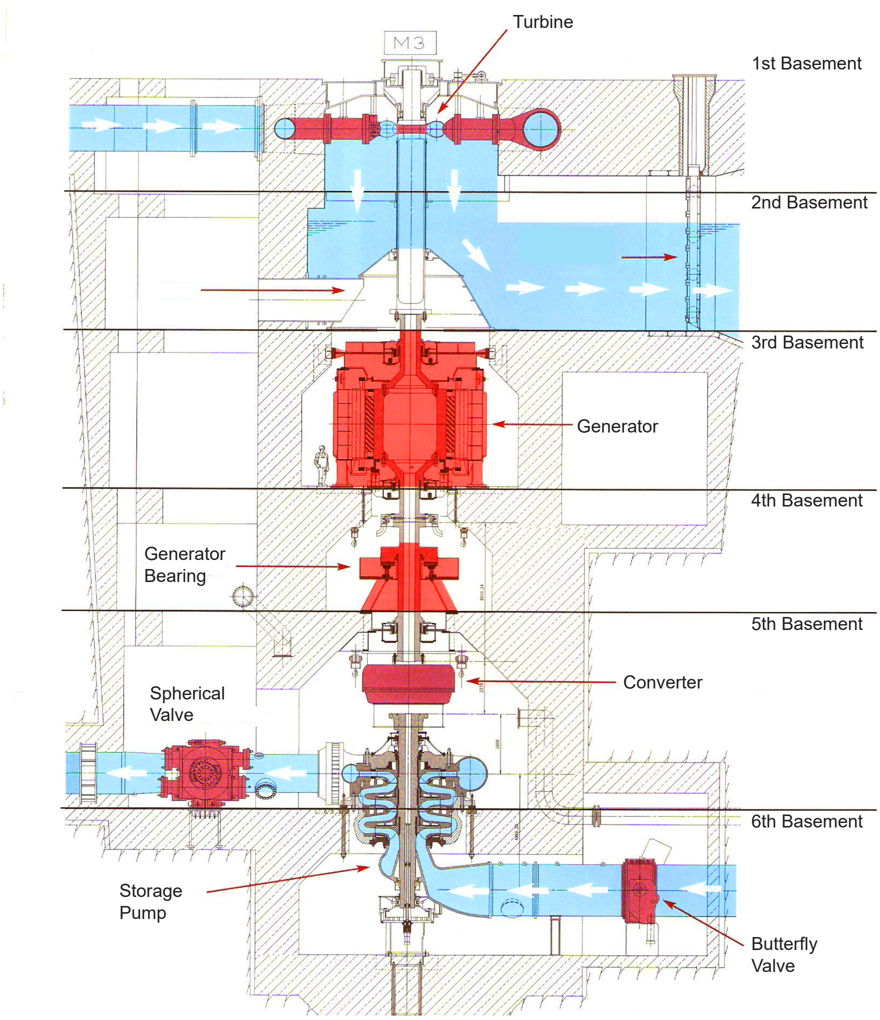
The Kopswerk II is equipped with three highly flexible and quickly regulating ternary machine units of 150 MW each, which can function as turbines or as pumps. The three vertical machine sets consist of a six-nozzle Pelton turbine, a synchronous motor/generator, a hydraulic converter and a three-stage pump.

Voith supplied the three complete units of equipment consisting of storage pumps and each with a spherical valves for Kopswerk II. The sets were specially designed for use in the short hydraulic circuit mode.

The storage pumps and turbines are separated and can therefore work simultaneously. In addition, three hydraulic torque converters were fitted at Kopswerk II. These allow switching the plant from non-operation into pump or turbine operation within seconds.

The six-nozzle Pelton turbine has a maximal flow rate of 25.3 m³/s at a water velocity of 460 km/h. However, the three-stage pump has a maximum pumping capacity of 19.3 m³/s and rated rpm of 500. The nominal generator power amounts to 200 MVA and in total 600 MVA.

The rated output in turbine operation makes up to 175 MW for each machine unit and in pumping operation 150 MW respectively. The conversion from turbine operation over to pumping operation needs approximately 60 seconds, the water column stops in 20 seconds and will be pressed against in 40 seconds. The water column weights around 110000 tons in the power waterway. The startup time for the energy transport amounts to around two minutes.



Machine unit of Kopswerk II [6]

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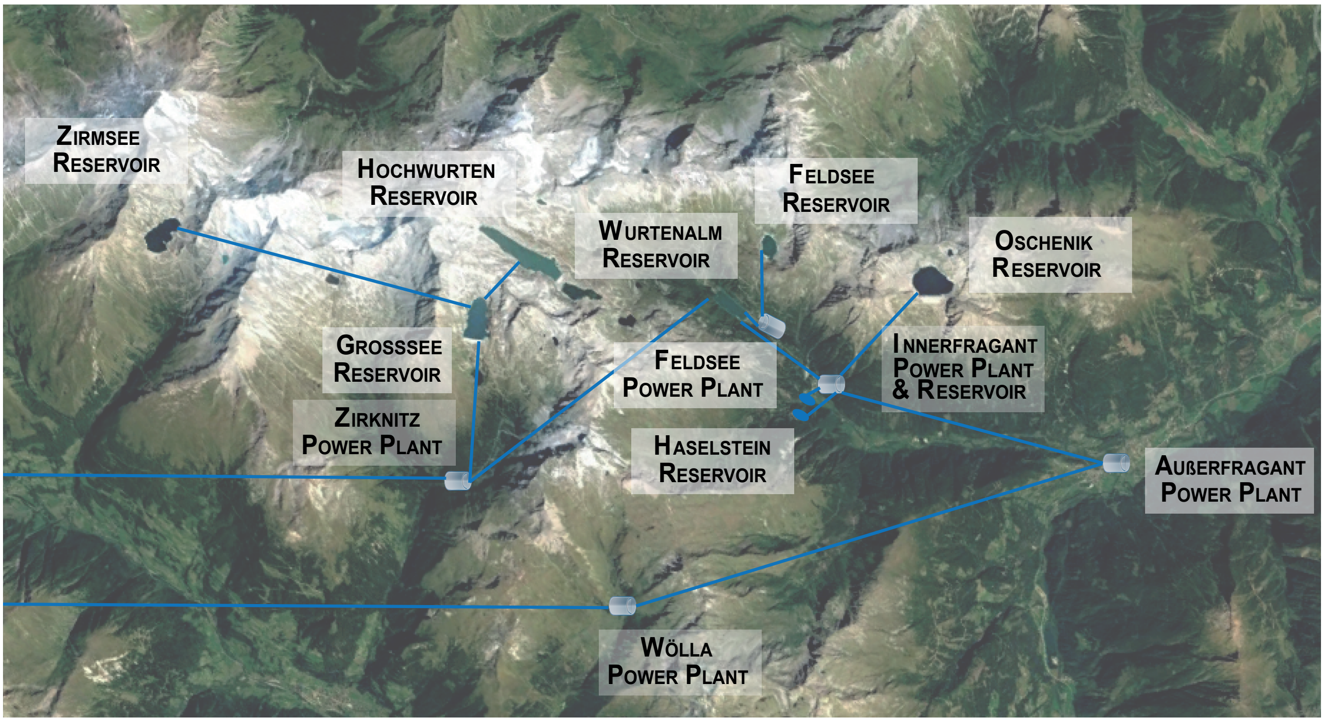
HYDROPOWER PLANTS FRAGANT



The power plant group Fragant is located in the Hohen Tauern mountains and consists of several run-of-river plants and storage plants. This unique system was build and extended beginning from 1963 to 1986 by the power company KELAG.

The hydropower plant group uses the Möll river water and the surrounded creeks. The Fragant hydropower plant group has a approximately total gross head of 1700 m.asl. The system consists of six storage lakes, three compensating reservoirs and five power houses as well as four storage plants and three run-of-river plants.

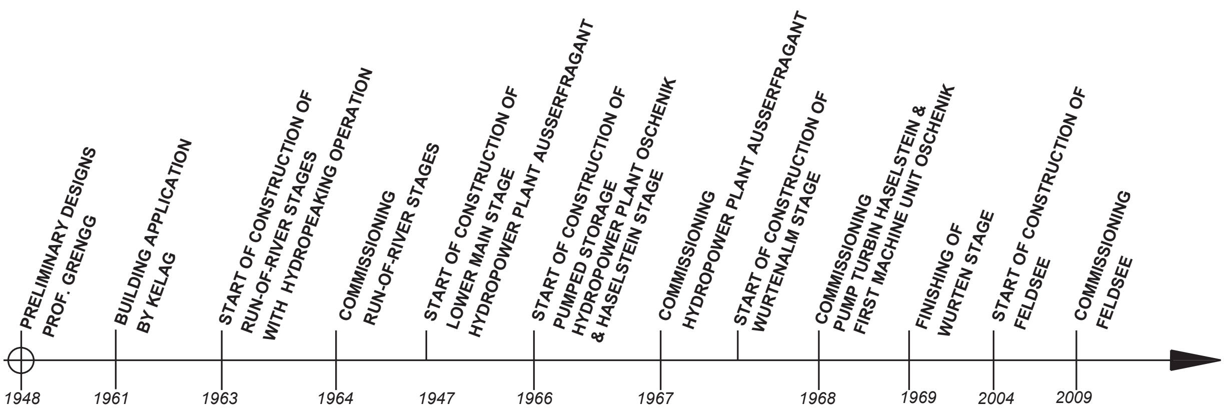
General the hydropower plant group consists of the preliminary stage, the main stage and the lower stage.

The power plant group annually produces about 840 GWh with a total installed capacity of 474 MW. The group has produced around 15 TWh electricity from 1965 until 2000.

In 2006, the KELAG extended the hydropower plant group with the pumped storage hydropower plant Feldsee. The first machine unit went in operation in 2009 and the second in 2011.

PRELIMINARY STAGE

The hydropower plant Zirknitz and Wölla are assoziate to the preliminary stage. Zirknitz is an annual storage power plant with the storage Großsee at Zirknitztal and the storage Hochwurten at Fragant.



Reservoir Feldsee [1]

The storage Hochwurten supplements the lower storage Weißsee, which is supplemented by the storage Schwarzsee. The Zirmsee at Fleißtal can supplement the Großsee through an open channel.

An open channel as well leads the tailwaters to the storage Wurtenalm. Wölla is a daily storage power plant and uses the water from the operational storage Wölla.

The storage Wölla gets water from several creeks at the northern Kreuzeck group. The Wölla tailwater flows to the storage Innerfragant. This water can further be pumped to the storage Oscheniksee or is lead to the hydropower plant Außerfragant.

MAIN STAGE

The main stage consists of the pumped-storage hydropower plants Feldsee and Innerfragant.

The pumped storage hydropower plant Feldsee uses the lower reservoir Wurtenalm and the upper reservoir Feldsee. Initially, the storage Feldsee was used as second storage for the storage Oscheniksee.

The pumped-storage hydropower plant Innerfragant in the first place uses the storage Oscheniksee. The Innerfagant tailwater is either collected at the storage Innerfragnat or lead to the hydropower plant Außerfragant.

The storage Haselstein located above the storage Innerfragand can be used in additional to the storage Oscheniksee. Excess water of the storage Haselstein can diverted to the storage Innerfragant.

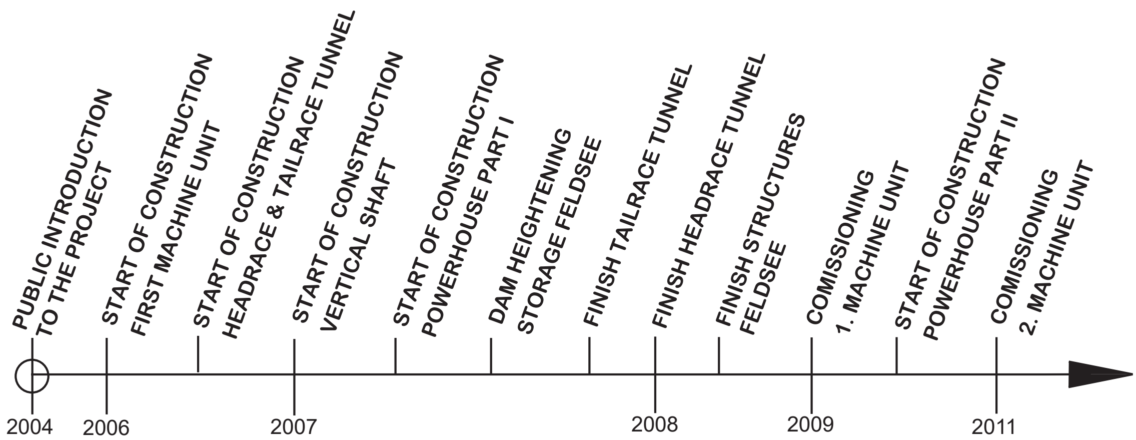
LOWER STAGE

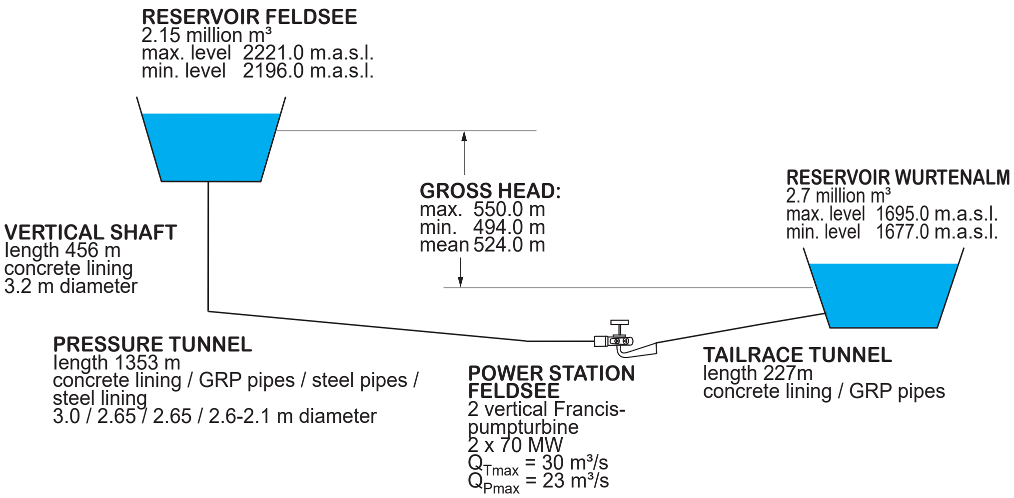
The lower stage consists of the hydropower plant Außerfragant. It uses the tailwater of the hydropower plant Wölla and Innerfragant.

FELDSEE

PUMPED STORAGE HYDROPOWER

Commissioning	2009		Live Storage **Wurtenalm**	2.7	[Mio. m³]
Machine type	Reversible Francis pump turbine		**Mean Gross head**	524	[m]
Discharge **Turbine**	30	[m³/s]	Installed capacity **Turbine**	140	[MW]
Discharge **Pump**	23	[m³/s]	Installed capacity **Pump**	140	[MW]
Live Storage **Feldsee**	2.15	[Mio. m³]	**Energy content**	3.24	[GWh]
Company	KELAG				





Hydropower scheme Feldsee

PLANT DESCRIPTION

The KELAG extended the power plant group by the pumped-storage hydropower plant Feldsee to increase the power output of the group. In summer 2009 the first machine unit got in operation and the second in 2011. The pumped-storage hydropower plant Feldsee utilizes the existing storages Feldsee and Wurtenalm. The reservoir Feldsee has a capacity level of 2221 m. asl with a live storage volume of 2.1 million m³ as the headwater reservoir. The reservoir Wurtenalm has a capacity level of 1699 m. asl with 2.7 million m³ live storage as the tailwater reservoir. At the lowest points of each reservoir are the intake and outlet structures are placed.

The power house is located on the valley side of the Wurtenalm reservoir. The tailrace tunnel connects the power house Feldsee and the Wurtenalm reservoir.

The pipeline is about 370 m long, partly underground and at some parts in a tunnel. The power house Feldsee has two reversible Francis pump turbines. The machine units produce around 300 GWh electrical energy per year and have a capacity of each 70 MW. The maximum turbine flow rate is about 30 m³/s and the pumping flow is about 23 m³/s. The 110 kV transmission line transports the energy to the outdoor switchyard Innerfragant.

Reservoir Feldsee in 2009 [1]

Reservoir Wurten in 2009 [1]

RESERVOIR MANAGEMENT

The pumped storage hydropower plant Feldsee is a daily-reservoir and a weekly-reservoir plant. The operation does not conflict with the natural water supply of the surrounding streams.

For the regular operation, it was originally considered a weekly schedule. Daily eight hours of turbine operation (29.4 m³/s) and seven hours of pump operation on working days (22.6 m³/s) as well as in total three hours of turbine operation and 21 hours of pump operation on weekend was specified.

The reservoir Feldsee is circulated about 100 times per year instead of twice. 120 to 140 times per year circulates the reservoir Wurtenalm instead of 40 to 55 times per year as originally intended.

The weekly level fluctuations of the Feldsee reservoir is up to 20 m and the daily level fluctuations is up to 12 m.

The storage Wurtenalm shows weekly level fluctuations of up to 17 m and maximal daily level fluctuations of up to 12 m. The pumped storage hydropower plant Feldsee increases the capacity of the hydropower plant group up to 27 % without the use of additional water sources.

The pumped storage hydropower plant has a annually production of 310 GWh.

Reservoir Wurten during construction in 2007 [1]

Adit portal in 2007 [1]

Construction site at the reservoir Wurten in 2007 [1]

POWER WATER CONDUIT

The headrace system consists of an intake and outlet at the Feldsee reservoir, a vertical shaft and a slightly inclined headrace tunnel which leads to the power house Feldsee. The tailrace tunnel connects the power house and the Wurten reservoir.

INLET / OUTLET STRUCTURE FELDSEE RESERVOIR

The two consisting reservoirs had to be draw down to the lower level to made the construction of the structure. The structure consists of a shut-off valve structure and a rake tower.

VERTICAL SHAFT

Pressure-Shaft		
Inner diameter	3.2	[m]
Excavated diameter	3.7	[m]
Height	456	[m]

The raise boring system was applied to build the vertical pressure shaft. The raise boring includes drilling a small pilot hole (D=350mm) down to the tunnel.

Construction site at the reservoir Wurten with the inlet/outlet and the spillway in shape of a trump in 2007 [1]

Raising drill pit in action [1]

A larger countersink is installed on the drill bar to bore upwards. The excavation falls to the bottom and is removed by a conveyor belt system.

Afterwards the system drilled the extension hole with a diameter of 3.7 m. The concrete lining was made by sliding formwork (D=3.2 m). The vertical shaft has a total height of 456 m.

HORIZONTAL-INCLINED HEADRACE TUNNEL

Headrace Tunnel		
Inner diameter	3	[m]
Excavated diameter	2.9	[m]
Length	1282	[m]

The headrace tunnel consists of three parts. The first section of the headrace tunnel has an inner diameter of 3 m. The second has an inner diameter of 2.9 m and the third is between 2.9 m and 1.1 m. The initial part of the tunnel has a 8 % inclination and is about 1282 m long.

The section between the initial tunnel part and the turbine supply line has 2.65 % inclination. The total length of the headrace tunnel is 1350 m. The starter tunnel is excavated using conventional drill and blast method. Four lining systems for the headrace tunnel has been selected. Which system depended on the rock mass quality, overburden and sealing requirement.

Linings of the penstock:

- Concrete lining (D=3 m)
- Glass fiber reinforced plastics pipes including inner concrete ring (D=2.65 m)
- Steel pipes including inner concrete ring (D=2.65 m)
- Steel lining (D=2.6/1.6/1.2/1.1 m)

Each lining system was backfilled with concrete.

TAILRACE TUNNEL

The tailrace tunnel connects the power house Feldsee and the reservoir Wurtenalm. It basically consists of two parts, one has concrete coated GRP pipes and the other has primarily GRP steel lining. GRP pipes close to the power house leads the distributor pipe.

Approximately 27 m after the intake/outlet Wurtenalm is the gate shaft including a roller gate.

Drilling jumbo at the tunnel in 2006 [1]

INTAKE/OUTLET STRUCTURE WURTEN RESERVOIR

The intake / outlet structure is located at the deepest point of the Wurten reservoir and very close to the portal area of the tailrace tunnel.

For inspection purposes, quick and easy to open by wooden dam beams, because they have just a sealing function.

Monitoring in the tunnel in 2006 [1]

Positioning of the spiral in 2010 [1]

Power house Feldsee in 2011 [1]

MACHINE UNIT

The installed machine unit is a reversible pump turbine with a maximum turbine capacity of 73 MW and a maximum pump capacity of around 69 MW. A spherical valve is installed at the high pressure side of the pumped storage hydropower plant and a shut off valve at the low pressure side. The three-phase synchronous motor generator has a capacity of 75 MVA with a nominal voltage of 10.5 kV.

Machine hall in the power house Feldsee in 2011 [1]

Construction site of the power house Feldsee in 2008 [1]

POWER HOUSE

The power house constructed as bunker includes the two machine units. The demanded submergence is 52 m at the below drawdown level and a flow rate of 11.3 m³/s, this was decisive for the placing of the power house. It has a total height of 32 m and a square layout of 21 m.

It consists of three ground floors and three upper floors. The whole machine unit ranges across all three ground floors. The machine hall with the dimensions 20 m/10.2 m/16.5 m (L/B/H) takes the biggest part of room in the power house. The building was finished in 2011 and took about 5 years of construction.

Shaft between the reversible pump turbine and the motor-generator in 2011 [1]

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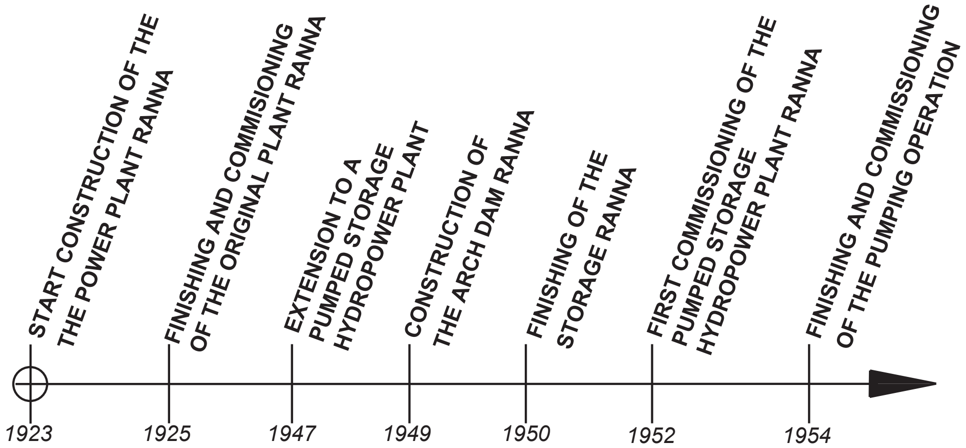
RANNA

PUMPED STORAGE HYDROPOWER

Commissioning	1954		**Mean Gross head**	199	[m]
Machine type **Unit I & II**	twin Francis spiral turbine with horizontal shaft		Installed capacity **Turbine Unit I & II**	7.9	[MW]
Machine type **Unit III**	twin Francis spiral turbine with horizontal shaft		Installed capacity **Turbine Unit III**	13.2	[MW]
Machine type **Unit IV**	Kaplan turbine with vertical shaft		Installed capacity **Turbine Unit IV**	0.9	[MW]
Headrace Surge Tank	Shaft surge tank		Installed capacity **Storage pump**	13.05	[MW]
Discharge **Turbine**	12	[m³/s]	Installed capacity **Feeder pump**	2.58	[MW]
Discharge **Pump**	6	[m³/s]	**Energy content**	1.06	[GWh]
Live Storage **Ranna**	2.35	[Mio. m³]	**Company**	*Energie* AG	



PLANT DESCRIPTION

The pumped-storage plant Ranna is located at the river Ranna in Upper Austria. The Ranna is a tributary to the Danube on the left bank and the power plant uses the flow from the Bohemian Highlands into the Danube and the high gradient of the Ranna to produce energy. The river has a catchment area of 166 km². The area is well wooded, partly mossy and mossy highlands with a huge water retention further uniform discharge. It uses the stored water of the Ranna. It is one of the oldest power plants in the Mühlviertel and started operating in 1925.

Power plant noticed the advantages of the gradient level early. Allready the owner of the castle Rannariedl built a small hydropower plant at the begin of the century. It is capable of pumping water from the Danube into the higher situated storage Ranna or reverse to produce energy. The power plant was built between 1923 and 1925 by Energie AG. The capacity of the plant could be increased from 5.8 MW to 19 MW by the establishment of the Ranna dam.

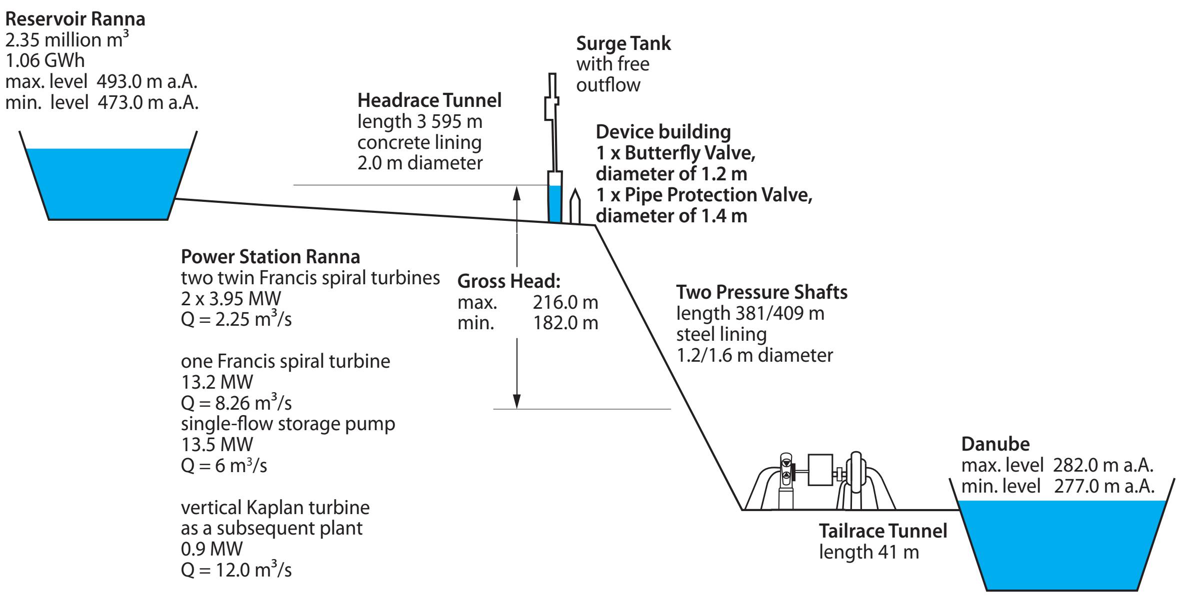
Today it is the second largest pumped storage hydropower plant owned by the company Energie AG. The average of annual production amounts to 47.7 GWh with a gross head of 220 m. From 1947 to 1954 the plant was stepwise extended to a pumped storage hydropower plant.

Through the almost 50 m high dam Ranna, with its 125 m crest dams up the Ranna almost 4 km until the valley Oberkappel, thus has a storage volume of 2.35 million m³ water and required 32000 m³ of concrete. In 1924, the first two machine units were installed, Francis dual-spiral turbines with horizontal shaft and each with 3.95 MW output.

The first expansion of the Ranna as high-pressure power plant was between 1923 and 1925 with a gross head of about 186.4 m, normal discharge of 4.5 m³/s and a capacity of 5.8 MW. A movable weir situated at the Ranna gorge was used to get a storage volume of 500 m³. A 3.6 km long headrace tunnel to the surge tank at the Donauhang and a pressure shaft further to the plant.

The power house is situated at the high shore of Danube about 8 m above the mean flow levels of the Danube. In 1947 the idea was born to build an arch dam instead of a weir and this dam was finished in 1950.

The arch dam Ranna is situated at the beginning of the valley Ranna that stores the four-kilometer long reservoir, which ends at the valley Oberkappel.



Hydropower Scheam Ranna

RESERVOIR MANAGEMENT

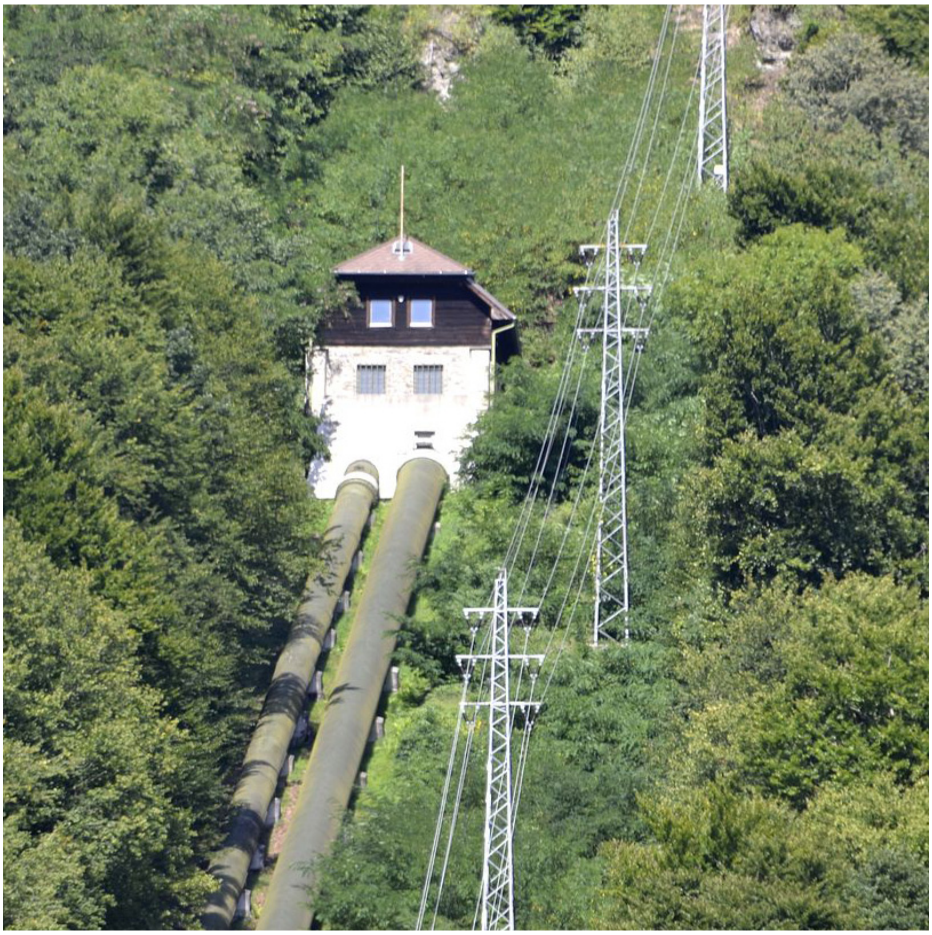
The power plant Ranna can generate power to cover peak consumption. This means that it will be put into operation when the electricity consumption rises suddenly and rapidly.

That plays a big role during the week as well as especially during the day and the storage fills up at weekends as well as during the night. In addition, the storage pump can transport 6 m³/s from the Danube to the reservoir.

The water from the Höllbach flows as well into the storage and thus a storage volume of about 2.35 million m³ is gained. The reservoir Ranna has an energy content of 1.06 GWh.

A 3.6 km long headrace tunnel leads the water from the storage to the two pressure shafts and from there it is further transported to the turbines.

After this first utilization, the water is lead to a Kaplan turbine to use the residual gross head to the Danube. The pumping operation is adjusted when good conditions in the power system and a decreased level at the storage are available. Thus, the produced energy can be saved and if required it can be emitted again. The required water can be taken from the Danube through the supply pump.



Device building of Ranna [2]

Aerial view of the power house Ranna and the switchyard [1]

POWER WATER CONDUIT

The headrace channel consists of the headrace tunnel, the surge tank, the device chamber and two pressure shafts. The pressure shaft is situated after the device chamber followed by the machine cavern and the supply pump.

INTAKE BUILDING & VALVE CHAMBER

The intake building is located at the west bank of the storage and contains a fine rake with cleaning system as well as a valve with a diameter of two meter.

HEADRACE TUNNEL

The tunnel the intake building and the valve chamber. The 3.6 km long underground tunnel has an diameter of 2 m, a gradient of 3 ‰ and leads to the surge tank above the machine cavern. The headrace tunnel has an normal discharge of 12 m³/s.

SURGE TANK & DEVICE CHAMBER

The following surge tank has a capacity of 730 m³. The device chamber consists of two shut-off valves and two pipe burst valves with a diameter of 1.2 m and 1.4 m respectively.

PRESSURE SHAFT

The device chamber is followed by the two pressure shafts. The shafts are made of steel and lead across the slope of the Danube valley to the machine cavern. The first shaft is riveted and still dates from the year 1925. This shaft leads the water to the two oldest machine units and have an diameter of 1.2 m across a length of 381 m.

The second one with an diameter of 1.6 m across a length of 409 m is welded and was put into operation in operation during the power plant expansion. It leads the water to the third turbine or from the storage pump in the direction of the storage Ranna. Finally, gravity drainage with a length of 41 m are constructed as a tailrace system.

POWER HOUSE

The machine cavern is located at the Danube in the locality of Kramesau, 2.5 km above the Ranna outlet into the Danube. A separate building beside the Danube was constructed for the feeder pump.

The pumped storage hydropower plant has 110 kV switchyard beside and is an important base for the energy supply of the upper Mühlviertel and the north Innviertel. The switchyard and a 110 kV cable connect the pumped storage hydropower plant Ranna and the around 20 km downstream the Danube situated storage hydropower plant Partenstein.

Both hydropower plants deliver peak energy via the switchgyard Wilhering and via the switchyard Wegscheid to the national grid. Until the beginning of 2012, the pumped storage hydropower plant Ranna was a regional control center as one of four. Today, it is controlled by the control center at Gmunden as all hydropower plants of the Energie AG.

Aerial view of the power station Ranna and the pressure shafts [1]

MACHINE UNIT

The pumped storage hydropower plant Ranna has 4 machine units and one feeder pump.

The main stage consists of the first two machine units, which are two twin Francis spiral turbine with horizontal shaft, a capacity of each 3.95 MW, a normal discharge of 2.25 m³/s and two synchronous 3-phase generator with each 4.5 MVA. The third machine unit is situated in the extended machine cavern.

The unit consists of a Francis spiral turbine with horizontal shaft, synchronous 3-phase generator with each 41.7 MW and a single-stage double-inlet storage pump with 13.05 MW and a normal discharge of 6 m³/s.

Machine unit number four is the downstream plant and consists of one Kaplan turbine with a vertical shaft. It has a capacity of 0.9 MW and a discharge of 12 m³/s.

Additionally, a cooling water unit with a Pelton turbine and the feeder pump with 2.58 MW and 6 m³/s are installed.

Ternary machine unit Ranna [1]

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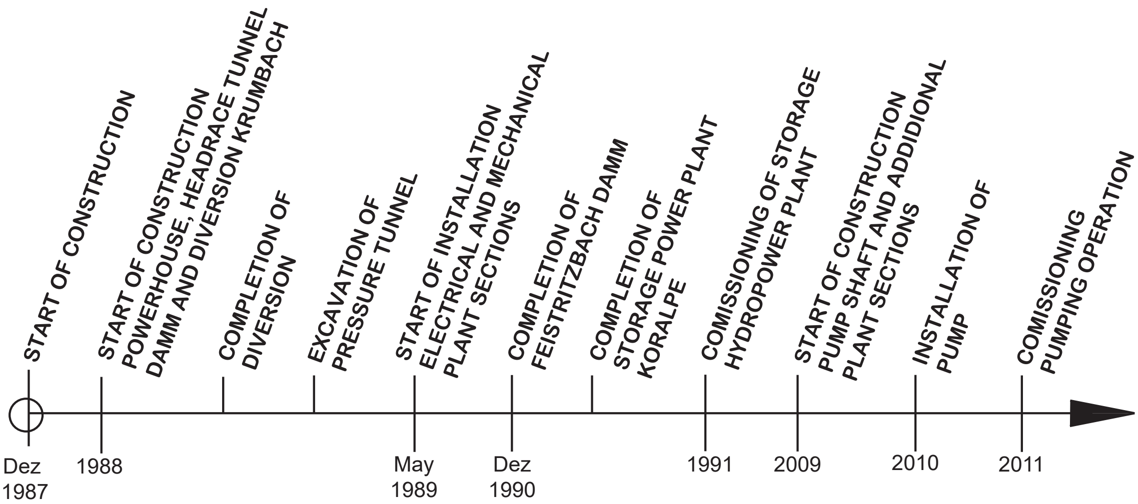
KORALPE

PUMPED STORAGE HYDROPOWER

Commissioning	2011				
Machine type	Pelton turbine with storage pump		**Mean Gross head**	735.5	[m]
Discharge **turbine**	8.0	[m³/s]	Installed capacity **Turbine**	50	[MW]
Discharge **Pump**	4.4	[m³/s]	Installed capacity **Pump**	35	[MW]
Live Storage **Soboth**	16.2	[Mio. m³]	**Energy content**	83.5	[GWh]
Company	KELAG				



PLANT DESCRIPTION

Reservoir Soboth [4]

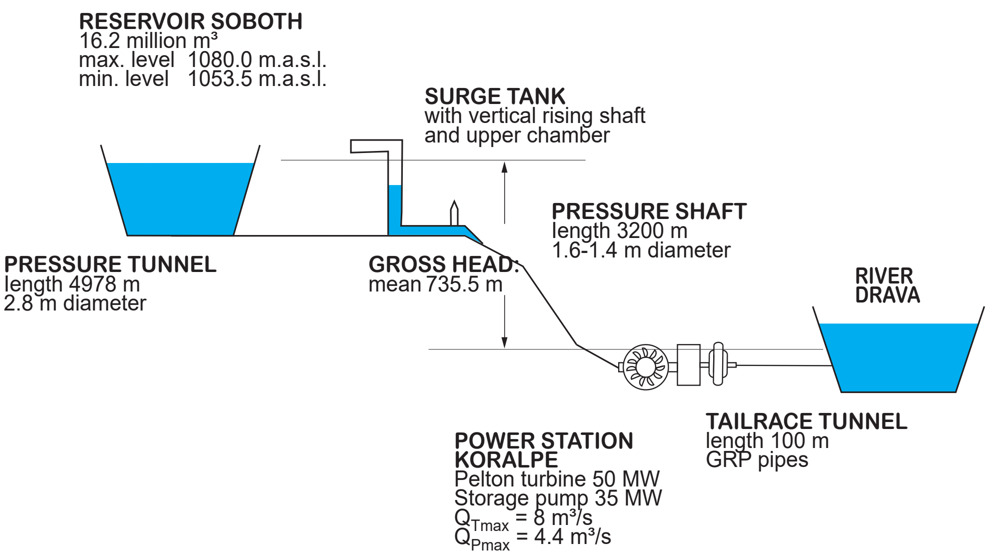
The storage plant was designed and built by Kärntner Elektrizitäts-Aktiengesellschaft (KELAG) at the border triangle of Carinthia, Styria both Austrian provinces and Slovenia. In 1960, the first research was carried out about the hydrographic and topographic parameters of the southern part of Koralpe. The purpose of this investigation was to find out how to use the volume of water from the Feistritz- and Krumbach as an energy source and the main investigations were carried out from 1970 to 1980.

Initially, one dam at the Feistritzbach and one dam at the Krumbach were scheduled and should be connected by a tunnel. Further investigations in 1983 determined unfavorable underground conditions in the range of the Krumbach and the second dam had to be cancelled. The construction of the dam Feistritzbach (Soboth) started in 1987. The 84 m high rockfill dam with asphalt core sealing forms the storage Soboth and is around 3 km long.

The rock filling amounts almost 1.7 million m^3. The water level of the storage is located at 1080 m.asl with 16.2 million m^3 live storage. In general, the storage is a winter storage and during summer it functions as a temporary storage with an annual water flow of 50 million m^3.

The system includes a pressure tunnel, a penstock, a spillway channel bottom outlet and measurement equipment for monitoring. The storage Soboth receives water through a 5.5 km long diversion tunnel from the Krumbach.

The core piece of the device is the power house Koralpe with remote features. In 2011, a pump shaft and a 35 MW pump extended the plant, while the existing Pelton turbine at power house Koralpe remained with 50 MW. Furthermore, a intake structure at the Drava and a pipeline to the pump shaft were renewed. Around 160 GWh of electrical energy has been produced every year since 2011.



Hydropower scheme Koralpe [4]

RESERVOIR MANAGEMENT

The basis of the past operating mode was characterized by hydrological required bottlenecks in the reservoir management. This result from requirements to hold the water level and otherwise from weather conditions.

Especially in winter, less snowfall and weak meltwater volume made it difficult to predict the current reservoir level. Therefore, deeper lowering of the reservoir level ad to be avoided and made an optimal reservoir management extremely difficult.

Before the upgrade to a pumped storage hydropower plant, the storage plant operated between 2500 hours and 2800 hours per year in the part-load operation and around 1800 hours full load operation.

The pumping operation raises the production from 83 GWh to 163 GWh during a normal year. This means an increase of 80 GWh, almost double the previous amount.

The pumping discharge of 49 million m³ and the previous storage discharge of 50 million m³ in a normal year raise the circulation form triple to six-times per year. In that regard, the pumping circulation operation will be for 94 % during the day or on weekends and just for 6 % operates on a seasonal basis.

The responsible water donation for the discharge in the diverted reach does not change. This concerns the creeks Krumbach and Feistritzbach, because of existing statutory conditions.

Similarly, no changes were made for the required and temporary frame for the minimum and maximum operation level. At the tailwater (the river Drava) are no significant impacts according to the pumping operation. The ratio of the discharge capacity between pump (4.35 m³/s) or rather turbine (8 m³/s) and the adjacently plants at the Drava Lavamünd (A) and Dravograd (SLO) with around 400 m³/s is just 1 to 2 %.

Upper reservoir Soboth [4]

Inlet structure at the river Drava [4]

GRP pipe [4]

POWER WATER CONDUIT

HEADRACE SYSTEM

The headrace tunnel with around 4980 m length leads from the storage Soboth to the valve chamber Magdalensberg. The tunnel has shut-off devices at both ends. The whole headrace tunnel has a concrete working lining, but partly steel lined. A shaping machine with a diameter of 3.5 m made the excavation.

The concrete coated and steel lined pressure shaft runs from the valve chamber to the power house at Lavamünd. The buried pressure shaft is 3.2 km long and has a diameter from 1.4 m to 1.6 m along the line.

CONNECTION TO THE EXISTING HEADRACE SYSTEM

High pressures of around p_{max} = 100 bar characterize this pipeline section. Forces from water changing direction in pipe and forces at the cap of the spherical valve must be derived through the shaft.

The connection to the existing headrace system had to conform to the hydraulically requirements of the hydraulic short circuit.

TAILRACE TUNNEL

A 100 m long tailrace tunnel connects the intake structure and the pump shaft. The pipe made of GRP (glassfiber-reinforced plastics) piping has a diameter of 2 m.

The excavation is near or below groundwater level. The sealing is a soilcrete jet-grouting wall at the loos rock area until the rock supply, as well as the pump shaft.

INTAKE STRUCTURE DRAVA

The intake structure of the pumped storage hydropower plant is situated on the shore of the river Drava. It is in the backwater area of the Slovenian power plant Dravograd and around 40 m downstream to the existing intake of the power plant Koralpe. During the construction, it was necessary to remove 6 t of war martial at the shore area. These concerned materials from the First and Second World Wars partly was still highly explosive.

Cofferdams with double-breasted sheet pile side and temporarily breakwaters fill saved the excavation pit. The level fluctuation area at the backwater of the power plant Dravograd and prevention of bed load entry influenced the height of the intake structure. A correspondingly large rake wide compensated the low intake height. A required warning chain for boater against possible turbulences was new.

POWER HOUSE AND PUMP SHAFT

The power house, located in Lavamünd, consists of a machine hall and the two adjoining company buildings and houses the six-jet Pelton turbine with an installed capacity of 50 MW. The machine hall is divided in a machine and an assembly block.

The pump shaft is right next to the power house in Lavamünd. The shaft has a depth of 35 m and a base area from 300 m^2 to 380 m^2. The sealing for the excavation were some soilcrete-jet grounding piles in the loose rock area. The pump shaft has 8 levels, whereby the inlet from the Drava is at the second level and the outlet to the storage Soboth is at the first level. The storage pump is situated at the sixth level right below the generator.

MACHINE UNIT

The electrical interior at the pump shaft consist of the storage pump, the necessary support facilities, the motor and control technology components as well as the 10.5 kV switchyard. The pump is a vertical, single-flow, triple-stage storage pump with a discharge of 4.5 m^3/s and an installed capacity of 35 MW.

The storage pump is the first triple-stage pump in the world, which blow up starts.

The turbine is a six jet Pelton turbine with vertical shaft and a discharge of 8 m^3/s and an included generator. The turbine has a capacity of 50 MW and the produced electricity is led by the 110 kV-cable to the switchyard, which is located beside the power house.

Plane view of the power station Koralpe [4]

Pump shaft Koralpe [4]

Pump shaft Koralpe under construction [4]

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