

# Pumped storage machines Reversible pump turbines, ternary sets and motor generators







# Harnessing the power of water

Generating electricity from the power of water represents large amounts of clean, renewable energy. Seventy-one percent of the earth's surface is covered by water. So far, the installed world's hydropower potential is 4 million GWh/year. There remains a huge hydropower potential of 16 million GWh/year.

- 1 Hongrin-Léman, Switzerland  
Source: Forces Motrices Hongrin-Léman SA, Switzerland
- 2 Upper reservoir Latschau, Rodund II, Austria
- 3 Rodund II, Austria

**Cover picture: Limberg II, Austria**

Hydropower is a clean, renewable and environmentally friendly energy source – with low carbon dioxide emissions. Hydropower plants have the highest operating efficiency of all renewable energy generation systems. They are largely automated, and operating costs are relatively low. Hydroelectric power plants also play an important role in water resource management, flood control, navigation, irrigation and in creating recreational areas.

#### **Customer focused and innovative**

Voith is a leading full-line supplier as well as trusted partner for equipping hydropower plants all over the world. Our portfolio of products and services covers the entire life cycle and all major components of hydropower plants:

- Generators
- Turbines
- Pumps
- Automation systems
- Spare parts
- Steel structural components
- Maintenance and training services
- Digital solutions for intelligent hydropower

#### **A world-class laboratory**

Using state-of-the-art technologies and innovative digital solutions, we are committed to developing customized long-term solutions in hydropower in the years to come. At the Voith Hydro Engineering Center, scientists, engineers and measurement technicians access more than 100 years of know-how and can make use of one of the most modern hydraulic laboratories in the world. Combined with the deep domain knowledge that evolved over decades from more than 40 000 units delivered to customers, this environment paves the way to innovations of the existing product portfolio as well as new technologies.

#### **Global experts**

As part of our international network, each Voith facility operates under the same cutting-edge platform and is equipped with consistent best-in-class processes and tools. This network also ensures that we can meet special customized requirements – from individual components to project planning, through project management and plant maintenance.

With branches and production facilities for electrical and hydraulic machines and components in Europe, Asia, North and South America, we are close to our customers and active in all major hydropower markets worldwide.

#### **Technical reliability with highest quality standards**

Voith has been known for quality right from the start. We strive to continuously meet our own high aspirations in terms of quality: Our global certification is based on well-known international standards (ISO) for quality management environmental protection as well as occupational health and safety. Moreover, we have developed our own methods for quality assurance and work according to them. In this way, future generations will continue to benefit from the quality of our work.





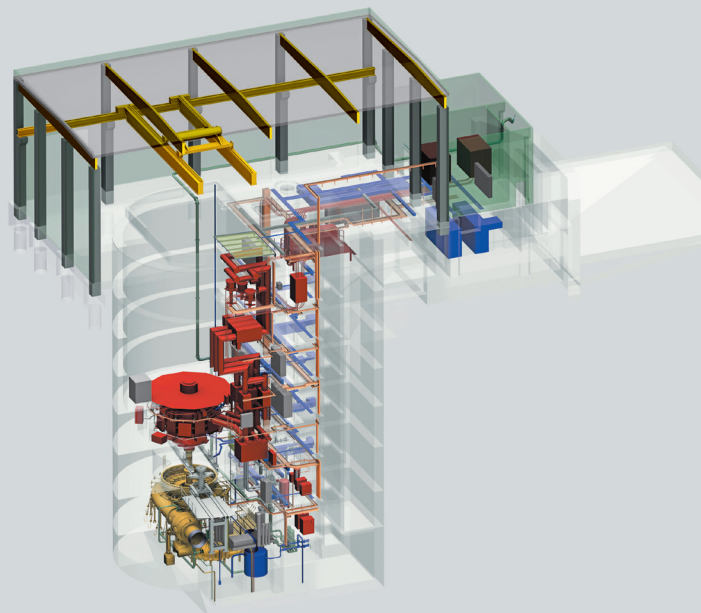
## Hydropower plant plus energy storage

Energy consumption is increasing rapidly. At the same time, it is becoming harder to keep energy production and consumption in balance at all times. As multi-functional power plants, pumped storage facilities have a high benefit for this challenge, because the technology behind them is the only long-term technically proven and cost-effective form of storing energy on a large scale, thereby making it available at short notice. Voith has more than 100 years of experience with pumped storage facilities and supplies the most modern and efficient plants in the world.





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4 + 5 Limberg II, Austria

6 3D model, Waldeck, Germany

The first pumped storage station in Germany was installed in 1908, when Voith constructed an uphill water storage tank for turbine tests in the Brunnenmühle and used it to operate pumps and turbines.

In 1937, Voith developed the first large, single-stage pump turbine, which operated both as a turbine for energy generation and, in the reverse direction, as a pump.

To meet the demanding requirements of a pumped storage plant, Voith applies a distinctive quality management. Each component is manufactured with the highest technical standard, e.g., shut-off valves, torque converters or clutches.

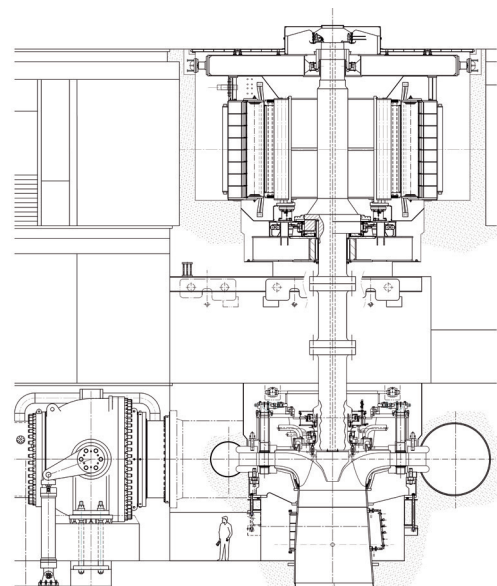
With regard to the plant's arrangement, Voith always finds technical solutions that improve the readiness for operation and a rapid transition from turbinning to pumping, and vice versa.

In supplying equipment for pumped storage plants, Voith gained a lot of experience in hydraulics over many years. A very large number of versatile Voith designs have proven extremely satisfactory in practical operation. In some cases, this experience covers many decades. It makes no difference whether the demand is for a reversible pump turbine or an optimally designed turbine and pump.

Nor is it of importance whether the pump turbine is equipped with a fixed or an adjustable distributor or whether, in the case of separate turbine and pump, a clutch operable at standstill, a starting turbine or a synchronizing torque converter permitting extremely short changeover times is to be provided.

Today, more than 450 Voith pumped storage units have been installed worldwide with a combined output of well over 60 000 MW. Whether a reversible pump turbine or a turbine and a pump combination, these machines have proven to be extremely durable. In many cases they have performed reliably for several decades.

#### Cross section of a pump turbine/generator unit





# Characteristics of reversible pump turbines

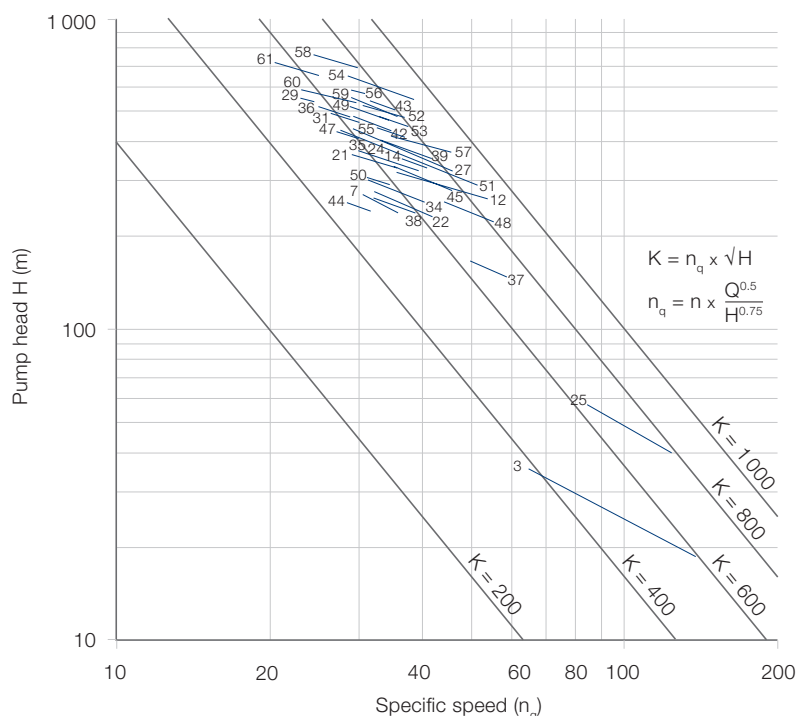
Progress in technology are constant, including the latest developments on variable-speed and wide head range applications.

Reversible machine sets consist of a motor generator and a reversible pump turbine that works either as a pump or as a turbine depending on the direction of rotation. Furthermore, a well-designed, compact power house saves equipment and civil costs. With a wide range of specific speeds, pump turbines can be installed at sites with heads from less than 50 to more than 800 m, and with unit capacities ranging from less than 10 to over 500 MW.

## Variable speed

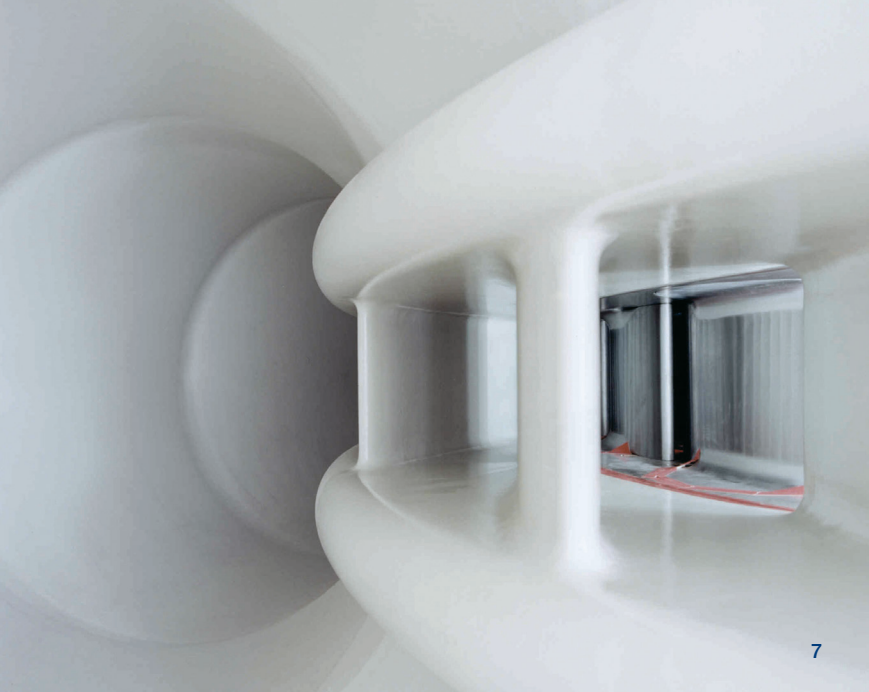
With the use of variable speed technology, by use of asynchronous motor generator or synchronous motor generator with frequency converter, the rotational speed of the pump turbine can be varied. Thus, the turbine operating range can be extended, the pump capacity can be adjusted to using just the currently available amount of energy. This technology stabilizes the grid efficiently.

## Selected pump turbines: operation range in pump mode

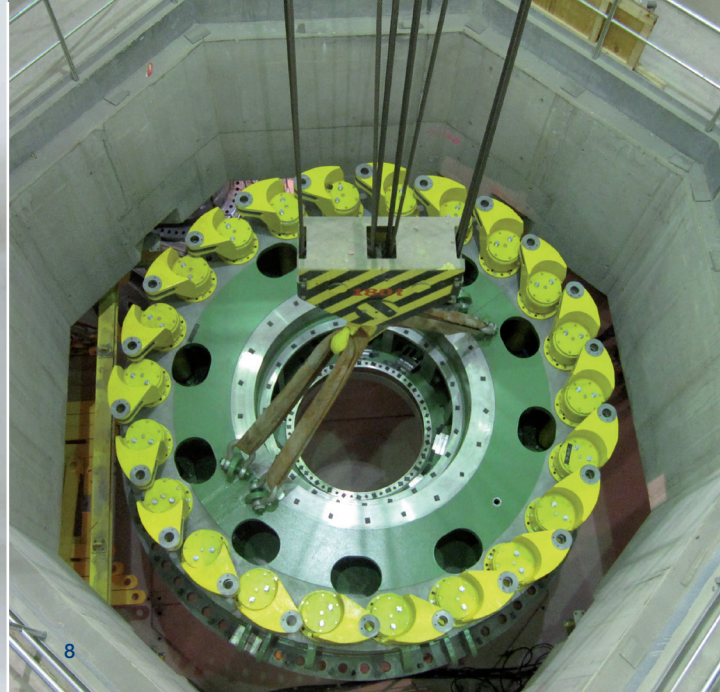


3 Lewiston	43 Guangzhou II
7 Coo I	44 Edolo (5 stage)
12 Raccoon	45 Goldisthal
14 Rodund II	(two variable speed)
21 Bath County	47 Venda Nova
22 Coo II	48 Tai An
24 Estangento	49 Siah Bishe
25 Gabriel y Galan	50 Waldeck I
27 Kühtai	51 Limberg II
29 Obrovac	52 La Muela II
31 Presenzano	53 Ingula
34 Palmiet	54 Reiseck II
35 Bad Creek	55 Frades II
36 La Muela	56 Hong Ping
37 Herdecke	57 Lamtagong
38 Chiotas (4 stage)	58 Chang Long Shan
39 Mingtan	59 TianChi
42 Shisanling	60 XiaMen
	61 Snowy 2.0 (fix speed)





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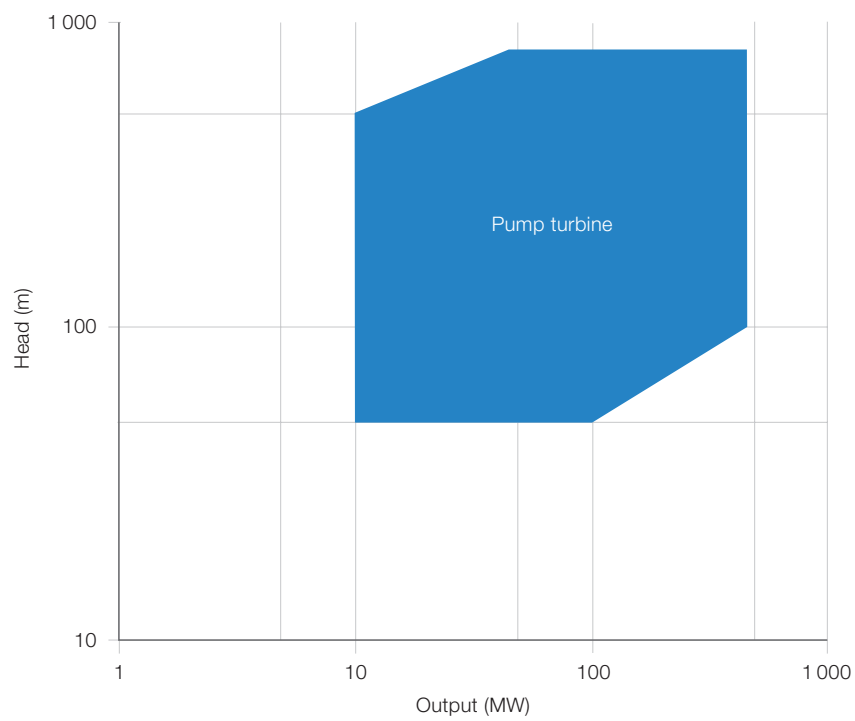


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7 Goldisthal, Germany

8 Limberg II, Austria

## Application range





# Characteristics of storage pumps and torque converters

Worldwide, Voith has earned a reputation as a major pump manufacturer. Many pumped storage plants work smoothly with Voith equipment. It's the efficiency and longevity that matters when running pumped storage plants. Our strength: reliable customized solutions.

Pumps for storage applications are mainly of the radial-flow type. Depending on the application conditions, the construction can be a single-flow or double-flow, as well as single-staged and multi-staged.

## Torque converter

The torque converter provides the most time efficient startup and shutdown of a storage pump. Within seconds the storage pump can be connected or separated from the shaft system.

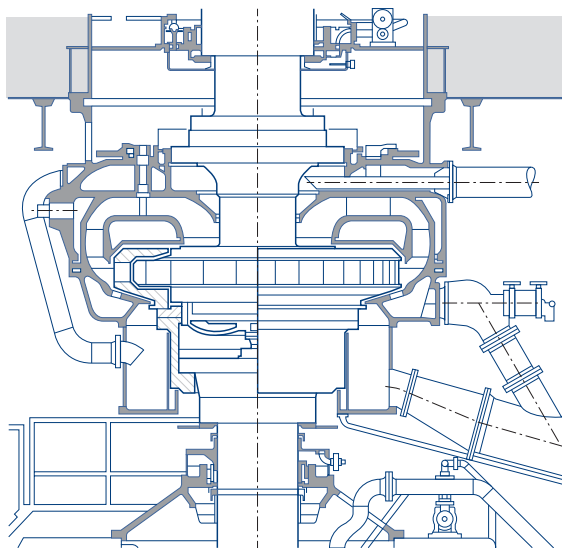
It transmits torque and/or power from the motor generator to the pump shaft by being filled with process water.

The start-up of the storage pump begins already during the filling process. As the pressure level of the filling water rises, the torque output by the converter increases and thus accelerates the pump.

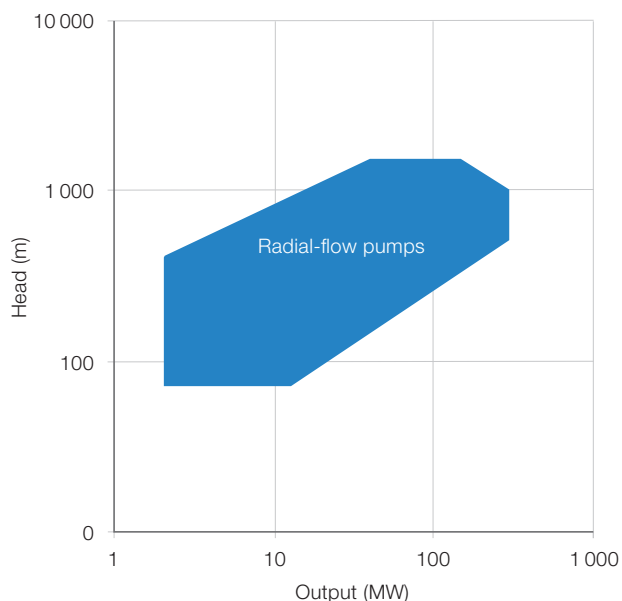
This acceleration torque, which is initially very high, continuously decreases as secondary speed rises. When reaching the synchronous speed, the converter output torque corresponds to the pump priming torque.

Due to the soft interaction of these processes, the storage pump can be started up quickly. No load surges for the grid occur.

## Hydraulic torque converter



## Application range radial-flow pumps



### Ternary sets

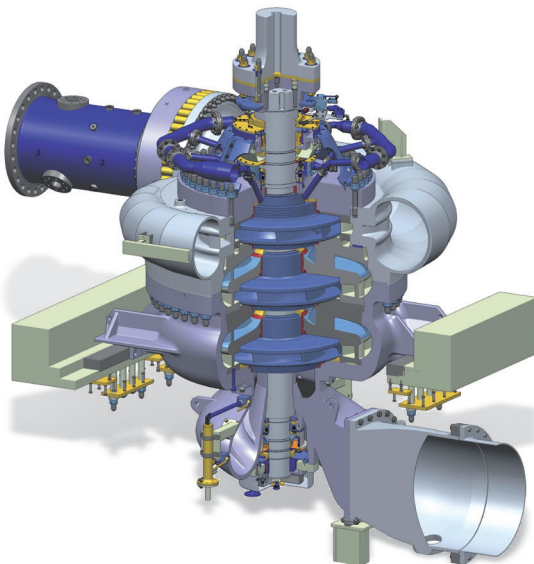
Ternary sets consist of a motor generator, a separate turbine (typically Francis or Pelton) and a pump set. As two separate hydraulic machines, the rotational direction of the motor generator can be the same in both operational modes. This results in considerable commercial value for the power plant's operation. For switching between turbine and pump operation, the following components can be provided: a clutch operable at standstill, a starting turbine or a synchronizing torque converter. With the configuration of a ternary set the, so-called hydraulic short circuit within the machine set can be implemented. It offers the best answer for a very fast grid response, being carried out with the torque converter which allows

fast change over between turbine and pump mode. Full regulating capability exists in both, the turbine and the pump mode operation from 0 % to 100 % of the unit output.

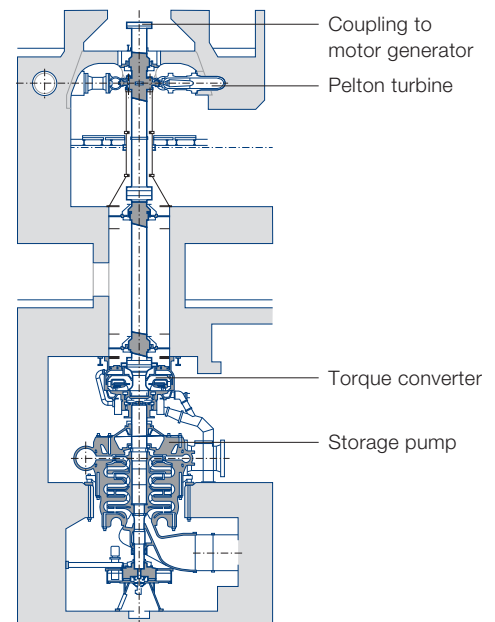
### Hydraulic short circuit

By using the hydraulic short circuit concept almost the full power range of the plant is available. Moreover, this application helps to control the energy flow into the grid. The principle of this operation mode is based on the idea that only the difference between the constant pump load and the flexible turbine output, both rotating on one common shaft, should come to the grid.

### 3D model, storage pump



### Ternary set





# Motor generator characteristics

Since the early beginning of manufacturing hydropower plants, Voith has supplied the world's largest and most powerful units in performance and size at their time. Voith always managed to go beyond limits.

Power demand increases with a growing economy and the improvement of living standards. Following this trend, the capacity of power supply units has increased continuously.

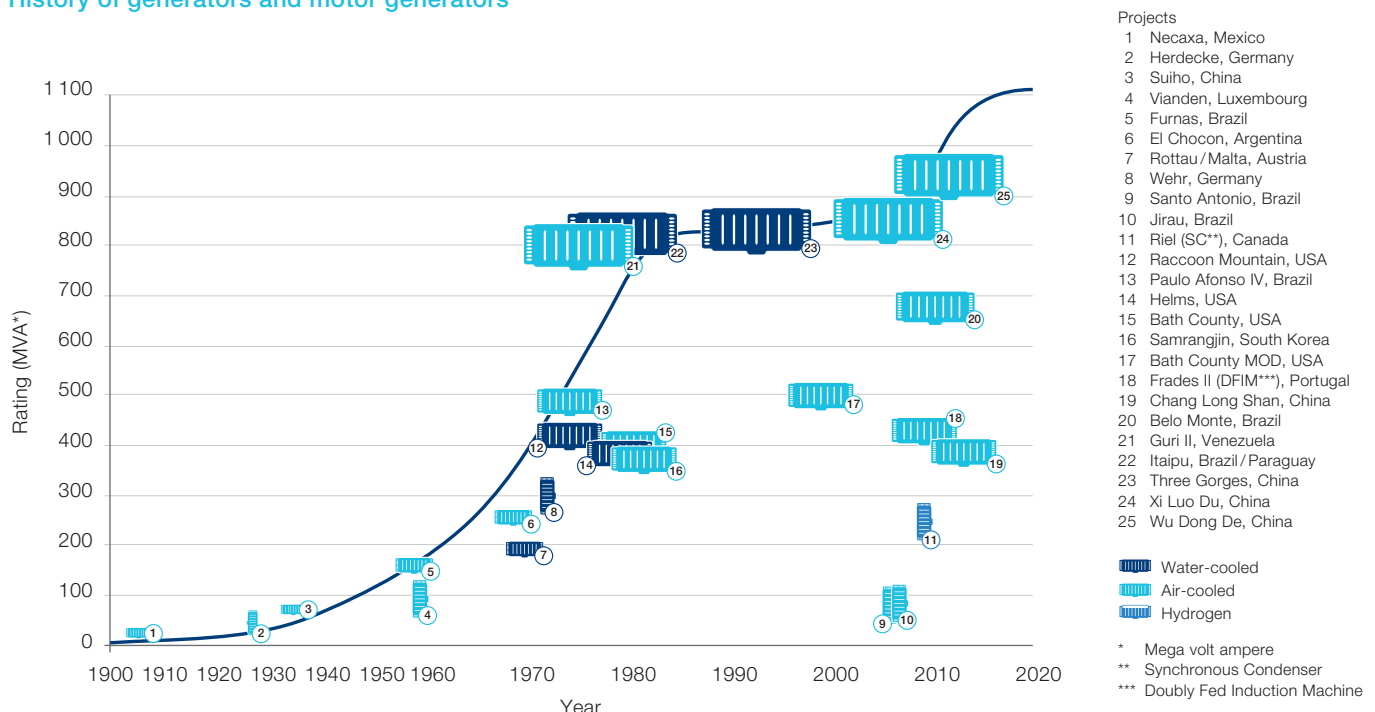
From the early 20<sup>th</sup> century, Voith has manufactured outstanding motor generators, for instance. The world's most powerful motor generators for Bath County (USA), delivered in 1976.

Or take the high-speed motor generators installed at Guangzhou II in China in 2000. These are among the largest of their kind.

## Our technology sets us apart

- Motor generator technology – including excitation, static frequency converters (SFC) and SCADA systems.
- Well advanced and proven VPI insulation system for optimized design for Class 155 according IEC (formerly Class F) and voltages up to 25 kV.
- Air-cooled by RIM-ventilation or forced ventilated, or direct water-cooling of stator winding and / or rotor winding and / or stator core.
- Magnetic thrust bearings for reduced torque during pump starts and reduced bearing losses during normal operation.
- Comprehensive system for automation of power station complex as a whole, including monitoring, remote supervisory control and data acquisition of the plant with fiber optic cable as required for control and station networks.
- Static frequency converter systems composed of computer duplex digital controller and optical thyristor of high-resistance voltage for high performance and easy maintenance.

## History of generators and motor generators



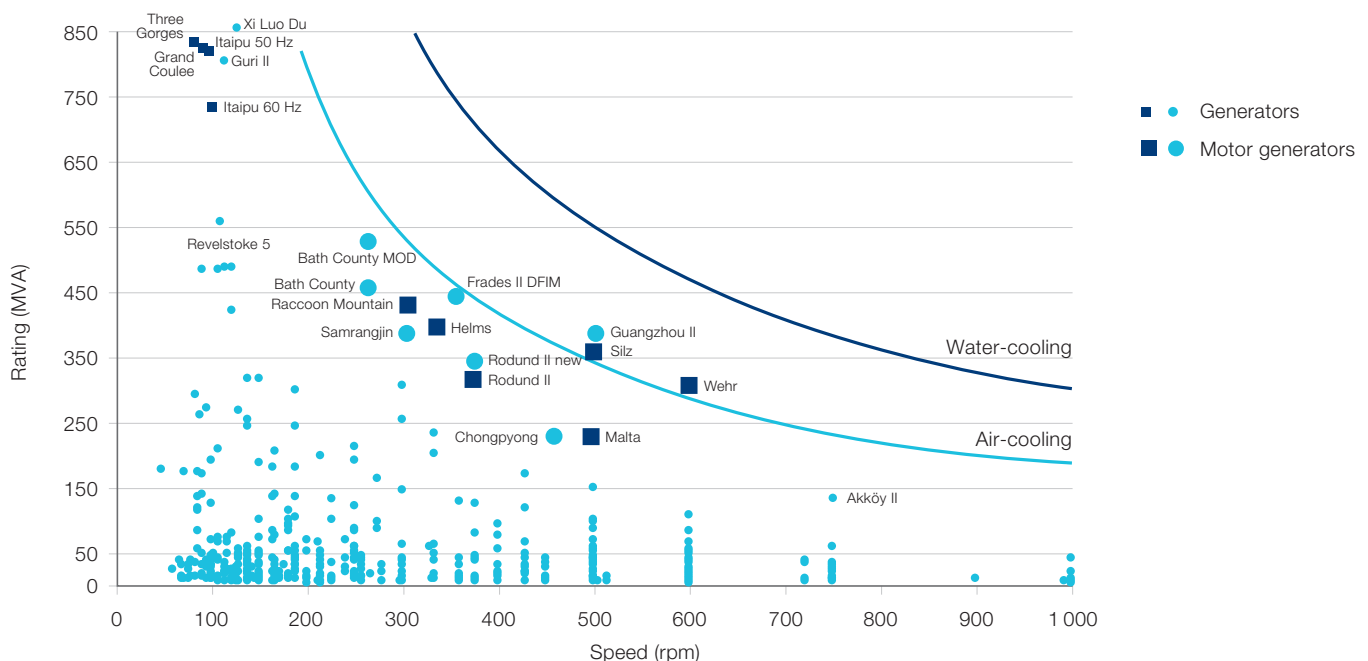
**The following design criteria influence the generator's main dimensions:**

- In order to ensure a long and reliable operation, it is essential that operational temperatures are aligned with the allowable limits of the materials, especially those of the winding with respect to the applied insulation system.
- The required moment of inertia must be provided within the given stator bore dimensions.
- At runaway speed the mechanical stress incurred by the rotating parts shall be designed within the maximum allowable stresses of the specific material and load universe for static as well as dynamic integrity.
- A safety margin is provided between the first critical speed and the unit's runaway speed. A shorter and lighter rotor helps to achieve this margin.
- For air-cooled machines, a shorter core length and a larger diameter might be suitable for uniform cooling along the entire core length and windings.

To achieve optimum economics, larger unit capacity machines are often being designed in order to reduce the number of units at each plant. In addition, high-speed rating is another important factor for smaller volume machines. Direct water-cooling is a very effective method in compact machines. Voith has vast references in both air-cooled and water-cooled machines as shown below.

All Voith generators are designed and manufactured with the latest state-of-the-art technology including the use of Vacuum Pressure Impregnation (VPI) for the stator bars and coils. Rated voltages up to 25 kV are part of our standard production.

**Generators and motor generators**







9 Reisseck II, Austria

# Mastering the challenges of changing energy systems

Today, the energy and grid industry is undergoing a rapid transformation. Trends such as distributed energy, renewables and digitalization are influencing increasingly complex network models and regulatory requirements. As multi-functional power plants, pumped storage facilities have a high potential to meet this challenge, as their technology is based on the only long-term, technically proven and cost-effective form of storing energy on a large scale.

Pumped storage plants supply the physically fixed base-load energy, but can also support the grid with rapid power changes in the event of forecast deviations and faults. This makes them a guarantee for grid stability and security of supply.

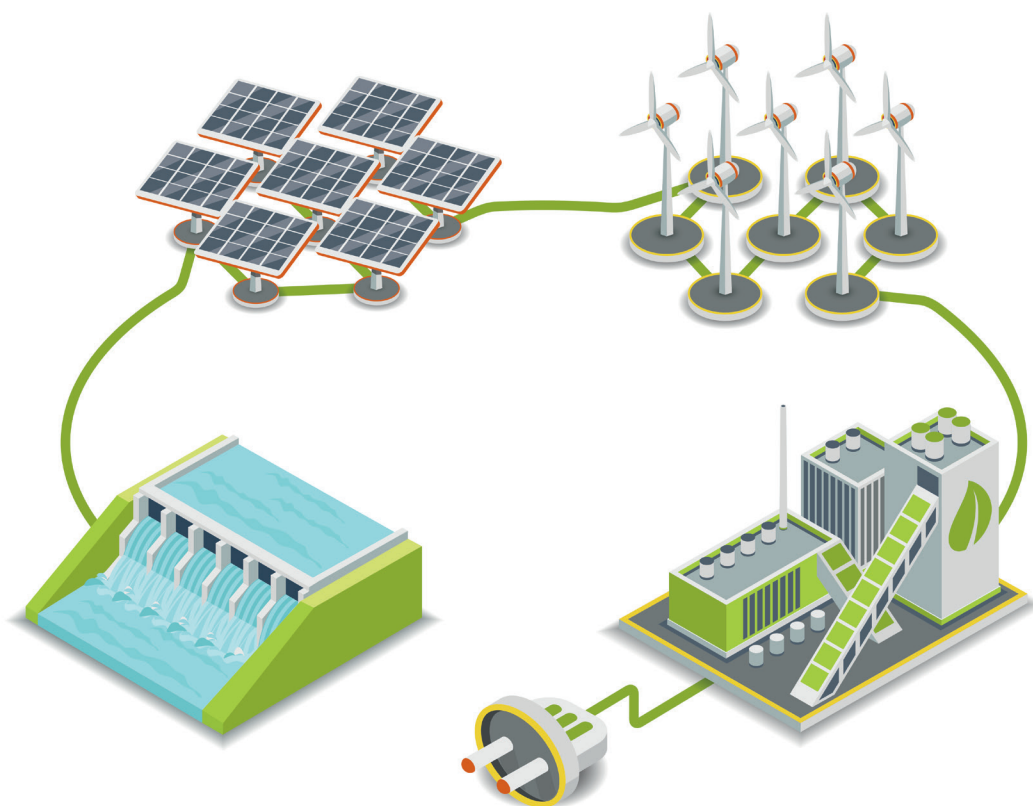
Pumped storage technology is needed to facilitate increasing quantities of variable renewables, which require a backup to ensure the stability of power systems.

Due to the increasing importance for the integration of renewable energies into the electricity market, Voith develops solutions for customers' renewable portfolio management. Our experts provide support for grid issues and complex grid modeling.

Combining wind mills and/or solar farms with a pumped storage plant – so-called hybrid solutions – ensures that the energy generated is immediately and reliably stored when it cannot be directly fed into the power grid.

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## Integration of renewables







## Reversible pump turbines and motor generators

### 1908 First pumped storage plant in Germany:

in Voith's hydraulic research laboratory, Brunnenmühle, Heidenheim.

### 1937 Pedreira, Brazil:

First reversible pump turbine in the world with an output of 5.3 MW, 30 m, 212 rpm.

### 1964 Roenkhausen, Germany:

First reversible motor generator unit in a German pumped storage plant.

### 1966 Coo-Trois Ponts 1, Belgium:

Three 145 MW, 270 m, 300 rpm pump turbines and motor generators.  
First reversible pump turbines in Belgium.

### 1970 Raccoon Mountain, USA:

Highest capacity pumped storage plant in the world at that time, with four 392 MW / 425 MVA, 300 rpm pump turbines and motor generators and with directly water-cooled stator and rotor.

### 1970 Vianden 10, Luxembourg:

One 230 MVA, 333.3 rpm motor generator.

### 1971 Wehr, Germany:

Worldwide highest synchronous speed for large motor generators with four 300 MVA motor generators and with directly water-cooled stator and rotor at 600 rpm.

### 1974 Rio Grande, Argentina:

Four 187.5 MW, 178 m, 250 rpm, pump turbines, inlet valves and 210 MVA motor generators.  
First reversible pump turbines in Argentina.

### 1974 Chiotas, Italy:

Two 4 storage 105 MW reversible pump turbines with a head of 1047 m.

### 1976 Bath County, USA:

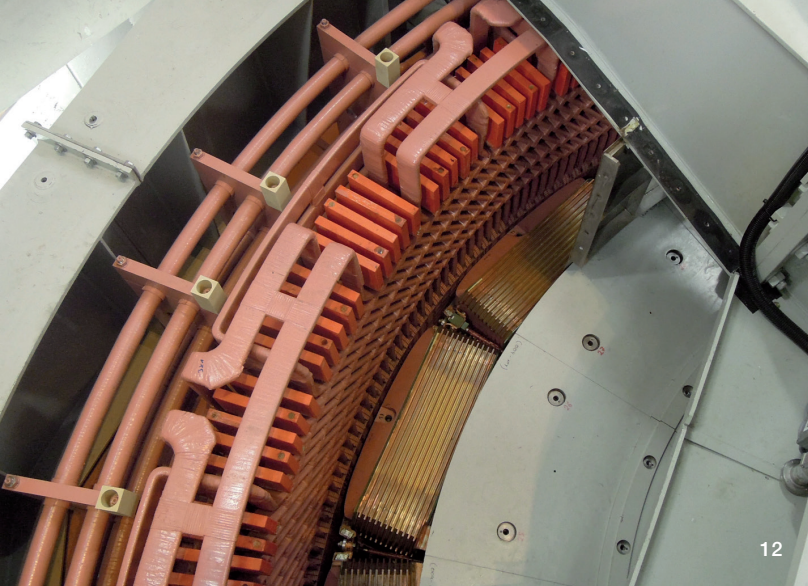
The world's most powerful pump turbines and motor generators at that time, six units with an output of 458 MW / 447 MVA, 329 m, 257 rpm.

### 1977 Helms, USA:

Three motor generators rated at 343.2 MW / 390 MVA, 360 rpm with directly water-cooled stator.

### 1977 Edolo, Italy:

Six 5 stage reversible 130 MW pump turbines with a head of 1 256 m.



10 Raccoon Mountain, USA

11 Guangzhou, China

12 Rodund II, Austria

13 Goldisthal, Germany

#### 1981 Samrangjin, South Korea:

Two 385 MVA, 300 rpm motor generators.  
The highest capacity reversible units in Korea.

#### 1983 Palmiet, South Africa:

Two 253 MW / 250 MVA, 301 m, 300 rpm  
pump turbines and motor generators.

#### 1992 Shisanling, China:

Four 204 MW, 430 m, 500 rpm pump  
turbines and inlet valves, providing reliable  
peaking power for China's capital.

#### 1994 Guangzhou II, China:

Four 306 MW / 380 MVA, 510 m, 500 rpm  
pump turbines and motor generators.

#### 1997 Ghatghar, India:

Two 139 MW, 445 m, 500 rpm,  
pump turbines and motor generators, enhancing  
the quality of India's electric energy supply.

#### 1997 Goldisthal, Germany:

Two 270 MW, 307 m, 333 rpm pump  
turbines for the most recent German  
pumped storage plant including variable-  
speed technology (300 – 346.6 rpm).

#### 2000 Venda Nova II, Portugal:

Two 106 MVA, 600 rpm motor generators  
and two 92.5 MV pump turbines.

#### 2001 Bath County, USA:

Refurbishment of stator windings and installation of  
new runners push these units to once again become  
the world's highest output pump turbines and motor  
generators at 480 MW / 530 MVA. Thus Bath County  
is the world's largest pumped storage plant with a  
total output of 3003 MW.

#### 2002 Tai An, China:

Four 278 MVA, 300 rpm motor generators  
and four 250 MV pump turbines.

#### 2004 Siah Bishe, Iran:

Four 300 MVA, 500 rpm motor generators  
and four 260 MV reversible pump turbines.

#### 2006 Limberg II, Austria:

Two 240 MW pump turbines with optimum  
design to meet wide head range application.

#### 2007 La Muela II, Spain:

Four reversible 213 MW, 600 rpm pump turbines  
and spherical valves, max. pump head 531 m,  
to deliver reliable power to the grid.





#### **2008 Ingula, South Africa:**

Supply of complete electro-mechanical equipment with four 342 MW / 373 MVA, 428.6 rpm pump turbines and motor generators.

#### **2010 Rodund II, Austria:**

One 295 MW, 375 rpm vertical reversible pump turbine and 345 MVA motor generator.

#### **2010 Reisseck, Austria:**

Two 215 MW, 580 m vertical reversible pump turbines.

#### **2010 Frades II, Portugal:**

Two reversible 372 MW pump turbines and Europe largest and powerful variable speed motor generators (DFIM) with 433 MVA and speed range 350 up to 381 rpm.

#### **2010 Hong Ping, China:**

Four reversible 306 MW pump turbines and 333 MVA, 500 rpm motor generators.

#### **2014 Lamtakong, Thailand:**

Two reversible 260 MW, 428 rpm pump turbines.

#### **2016 Chang Long Shan, China:**

Two reversible 357 MW, 600 rpm pump turbines.

#### **2017 Qing Yuan, China:**

Six reversible 306 MW, 375 rpm pump turbines.

#### **2017 Tian Chi, China:**

Four reversible 306 MW, 500 rpm pump turbines.

#### **2018 Xia Men, China:**

Four reversible 357 MW, 428 rpm pump turbines.

#### **2019 Snowy 2.0, Australia:**

Three synchronous reversible 340 MW, 500 rpm pump turbines and three asynchronous reversible 340 MW pump turbines with a speed range of 455 to 523 rpm.



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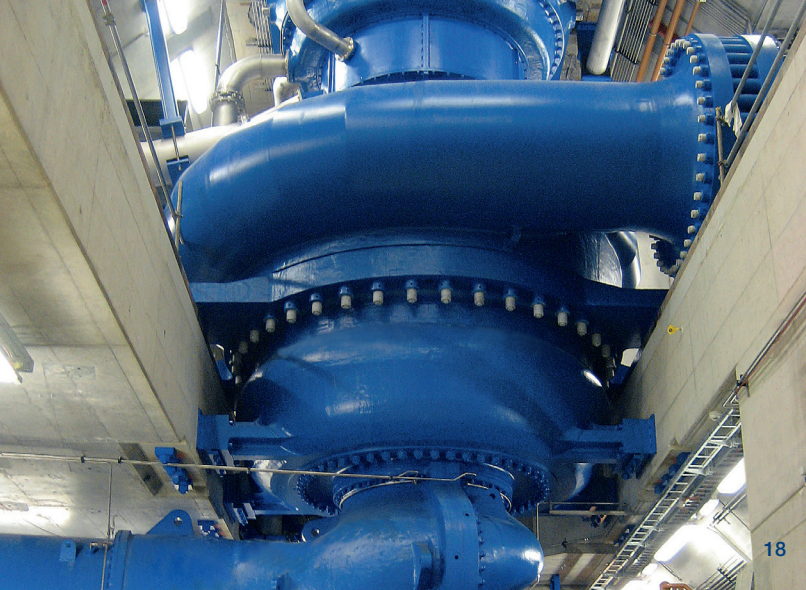
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- 14 Frades II, Portugal
- 15 Ingula, South Africa
- 16 Shisanling, China
- 17 La Muela II, Spain

## Storage pumps

- 1928 Niederwartha, Germany:**  
Two horizontal radial pumps.  
P: 20.5 MW, H: 154 m.
- 1954 Luenersee, Austria:**  
First pump with a head exceeding 1 000 m.
- 1964 Säckingen, Germany:**  
Four horizontal two-stage back-to-back arranged radial pumps.  
P: 70 MW, H: 410 m.
- 1967+ Roßhag, Austria:**  
**1973** Four vertical two-stage radial pumps.  
P: 52 MW, H: 690 m.
- 1967+ Tehachapi, USA:**  
**1979** Ten vertical four-stage radial pumps.  
P: 57 MW, H: 600 m.
- 1970 Hornbergstufe-Wehr, Germany:**  
Four horizontal two-stage double suction radial pumps for pumped storage.  
P: 250 MW, H: 666 m, Q: 36 m³/s.
- 1973 Malta Hauptstufe, Austria:**  
Two storage pumps equipped with synchronizing converters with gear coupling.  
P: 140.7 MW, H: 1100 m.
- 1981 Häusling, Austria:**  
Two storage pumps equipped with synchronizing converters with gear coupling.  
P: 178.5 MW, H: 726 m.
- 1990 Säckingen, Germany:**  
One storage pump as a replacement of one storage pump delivered in 1964.  
P: 84.4 MW, H: 410.8 m.
- 1992 Riva del Garda, Italy:**  
One storage pump consisting of mixed-flow booster pump (H: 27 m) and radial flow pump (H: 543 m, three stages) connected to the shaft line of a Pelton turbine and motor generator.
- 1992 Yang Zhuo Yong/Tibet, China:**  
Four storage pumps with 19.1 MW each, six stages with gear coupling for connection in standstill.
- 1999 Pont Ventoux, Italy:**  
One storage pump connected to the shaft of a splitter type Francis turbine with gear coupling.  
P: 73.4 MW, H: 519 m.





**2004 Kops II, Austria:**

Three vertical three-stage radial pumps for pumped storage.  
P: 152 MW, H: 784 m.

**2008 Koralpe, Austria:**

One vertical three-stage radial pump for pumped storage.  
P: 38 MW, H: 740 m.

**2011 Hongrin Léman, Switzerland:**

Two vertical five-stage radial pumps for pumped storage.  
P: 118 MW, H: 865 m.

**2014 Obervermunt 2, Austria:**

Supply of two one-stage storage pumps.  
P: 170 MW, H: 290.4 m.

**2017 Häusling, Austria:**

Modernization of the two two-stage storage pumps delivered in 1981. P: 207 MW, H: 635 m.

**2018 Malta Hauptstufe, Austria:**

Modernization of two four-stage storage pumps delivered in 1973. P: 194.5 MW, H: 1100 m.

**2018 Ritom, Switzerland:**

Supply of one two-stage storage pump.  
P: 61.2 MW, H: 711 m.

**2019 Wan Jia Zhai HLP, China:**

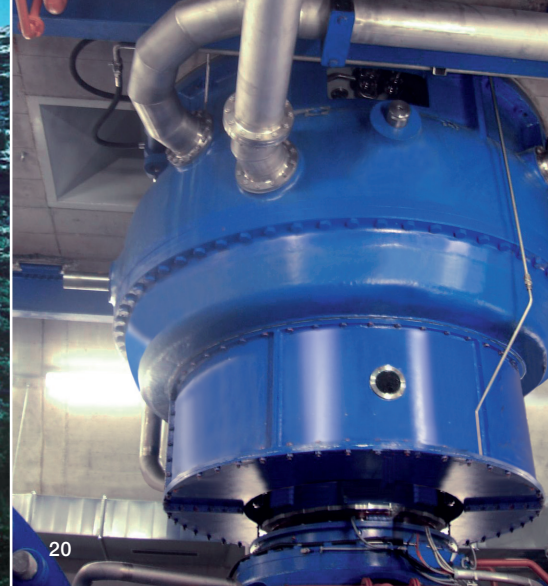
Supply of 14 one-stage storage pumps.  
P: 10.5 MW, H: 140 m.

**2019 Wan Jia Zhai LLP, China:**

Supply of five one-stage storage pumps.  
P: 5.5 MW, H: 76 m.

**2019 Hattelberg, Austria:**

Supply of one one-stage storage pump.  
P: 16.4 MW, H: 1105 m.



18 Storage pump, Kops II, Austria

19 Kops II, Austria

20 Torque converter, Kops II, Austria

## Torque converters

### 1954 Luenersee, Austria:

Five torque converters in vertical arrangement for pump start-up.  
P-Converter: 33 MW.

### 1964 Säckingen, Germany:

Four horizontal arranged torque converters,  
P-Converter: 40 MW.

### 1967+ Roßhag, Austria:

1973 Four vertical arranged torque converters,  
P-Converter: 31 MW.

### 1970 Hornbergstufe-Wehr, Germany:

Four horizontal arranged torque converters with the highest converter power today,  
P-converter: 150 MW.

### 1973 Malta Hauptstufe, Austria:

Two vertical arranged torque converters,  
P-converter: 75 MW.

### 1981 Häusling, Austria:

Two vertical arranged torque converters,  
P-converter: 100 MW.

### 2004 Kops II, Austria:

Three vertical arranged torque converters,  
P-converter: 80 MW.

### 2014 Obervermunt 2, Austria:

Two horizontal arranged torque converters.  
P-converter: 45 MW.

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