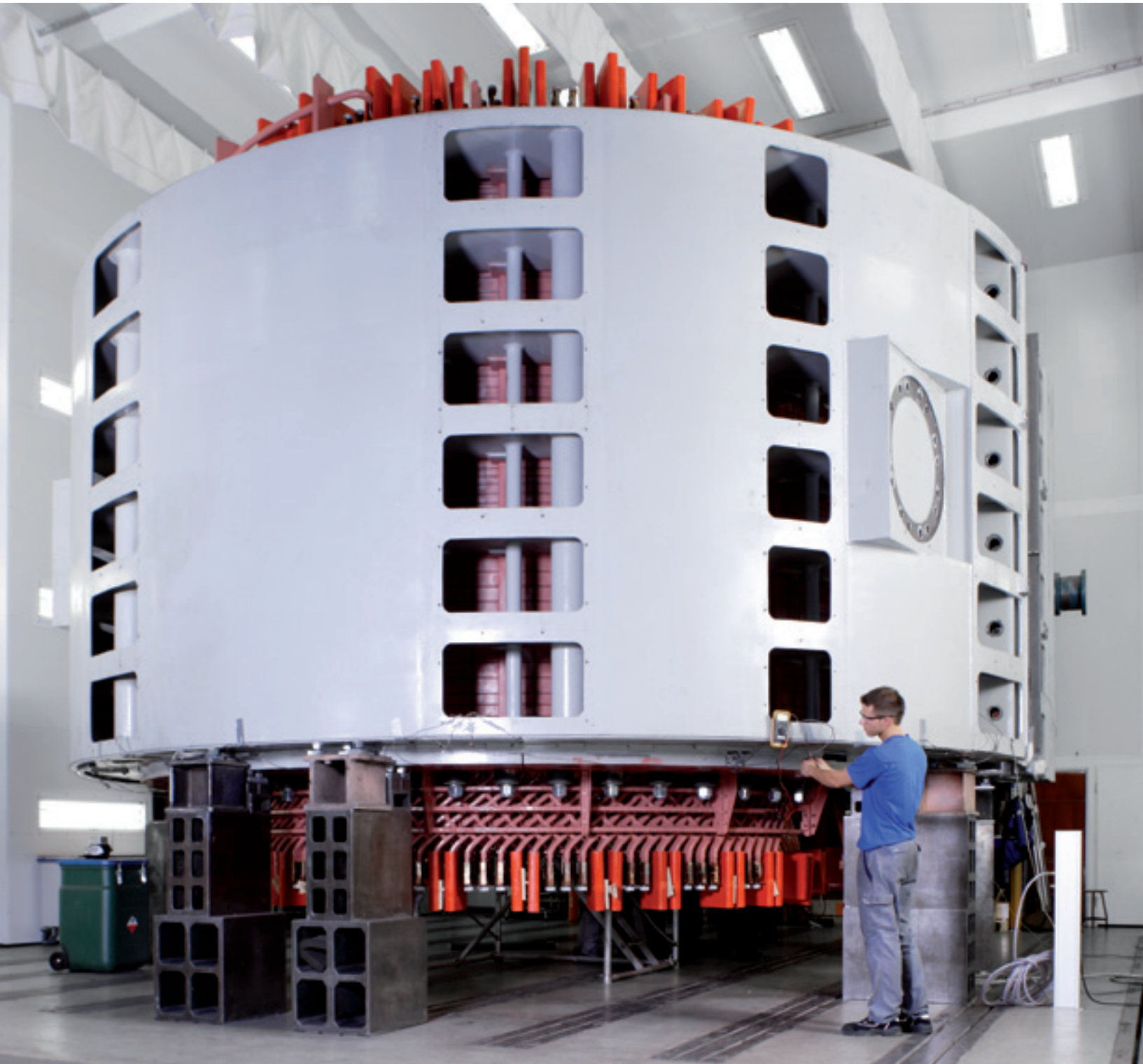
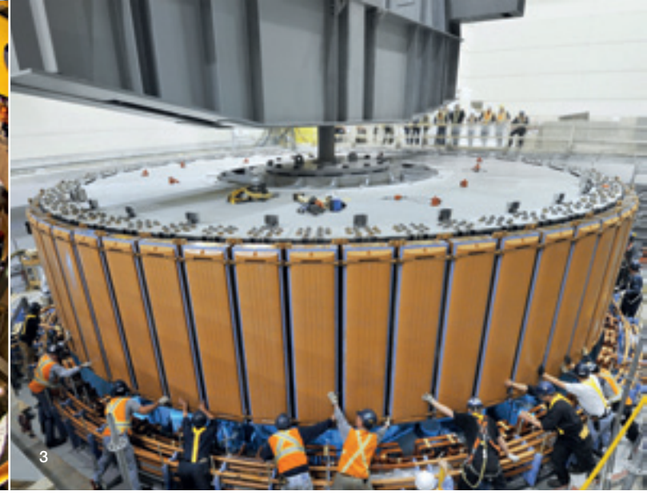
VOITH

Generators





Cover picture Wehr, Germany

1 Guri, Venezuela
2 Xi Luo Du, China
3 Revelstoke, Canada

Harnessing the power of water

Generating energy from the power of water represents large amounts of clean, renewable energy. 71 percent of the earth's surface is covered by water. The world's hydropower potential amounts to an estimated 20 million GWh/a and only 25 percent of this has been developed so far.

Hydropower is not only environmentally friendly, but also cost-effective. Hydropower plants have the highest operating efficiency of all renewable generation systems. They are largely automated, and their operating costs are relatively low. Hydroelectric power plants also play an important role in water resource management, flood control, navigation, irrigation and in creating recreation areas.

Voith is an industry leader in the production of generators, turbines and the associated control systems to put the power of water to work. A range of services, from engineering through manufacturing and project management to commissioning, completes our portfolio as one of the world's leading hydropower product and service provider.

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 electric 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.

With more than 140 years' experience in the field of hydropower and high annual spending for research and development, Voith is well equipped to continue delivering excellence in hydropower in the years to come.

Engineered reliability
Is our promise to our customers. Our products and services are designed specifically for our customers' needs. Always efficient and economical and, above all, following our values and visions for sustainable hydropower solutions.

Competences and capabilities

- Consulting, engineering, erection and commissioning
- System/plant assessments
- HyService – global, fast and effective for modernization and rehabilitation of existing hydroelectric power plants
- Complete equipment, installation and services for hydroelectric power plants
- Francis, Pelton, Kaplan, Bulb/Pit/S-turbines, pump-turbines, standard and customized products
- Storage pumps, radial, semi-axial and axial-flow pumps
- Generators and motor-generators for constant and adjustable speed, excitation systems
- Frequency converters, protection systems, switchyards for all voltages, transformers
- Power plant automation, control centers for hydropower plants and cascades, including plant management and diagnostic systems
- Shut-off valves
- Integrated Management System to safeguard excellence and quality

Characteristics

For well over a century, Voith has supplied the world's largest and most powerful hydroelectric units with respect to both performance and size. As we push the envelope in hydropower technology, Voith focuses on customized solutions for utilities.

Power demand increases with the expansion of the economy and improved living standards. Following this trend, the capacity of generating units has also increased, growing from 6.25 MVA at Necaxa in 1903 up to 840 MVA at Three Gorges in 1997 and now to more than 855.6 MVA at the Xi Luo Du power station which are the most powerful generators designed and manufactured by Voith today.

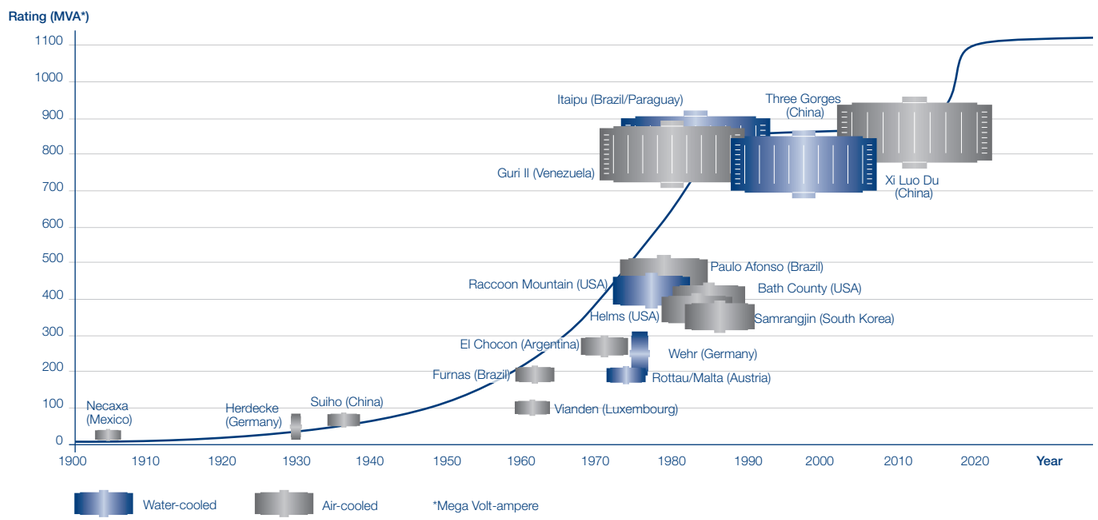
To improve optimum project economics, higher unit capacity machines are often used in order to reduce the number of units at each plant. For compact machines, direct water cooling is very effective. Within the renewable energies, pumped storage plants play a new role: with the use of variable speed technology to directly support grid control.

Frades II is a milestone in hydropower: thanks to their variable speed based of DFIM (Doubly Fed Induction Machine), the pumped storage units designed and supplied by Voith can adapt their number of revolutions continuously and take or provide power from and to the grid.

Above this, the asynchronous motor-generators can also be utilized for frequency stabilization of the grid. The highly sensitive control systems react to grid variations within milliseconds, can tap the kinetic energy of the flywheel masses of the motor generators, and provide immediately energy to the grid, or respectively absorb energy from it. Facing variations in the grid, the motor generators react extremely fast and in the case of faults can compensate voltage drop accordingly – and thus enhance security of power supply.

With a maximum continuous output of 433 MVA and a speed range from 350 rpm to 381.2 rpm those will be the most powerful variable speed motor-generators in Europe built so far.

History of generators and motor-generators



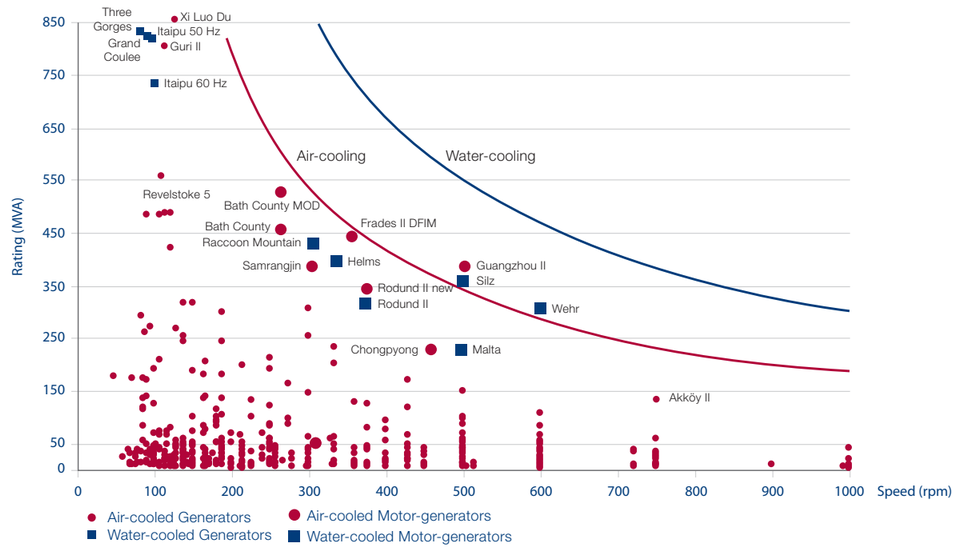
Design criteria

Voith is setting milestones with its Generator technology. Customers benefit from our deep understanding of sophisticated engineering and conceptual competence in project execution.

And at the same time our engineers incorporate the cause and effects of the related components o the entire plant.
We master the interplay of thinking outside the box and traditional engineering in order to provide a highly reliable generator that offers the state-of-the-art technology. We keep in mind what customers are looking for: efficiency, easy handling, absolute reliability.

One of the most powerful synchronous Generators is the Xi Luo Du power plant in China with a maximum output of 855.6 MVA at 125 rpm.

Generators and motor-generators



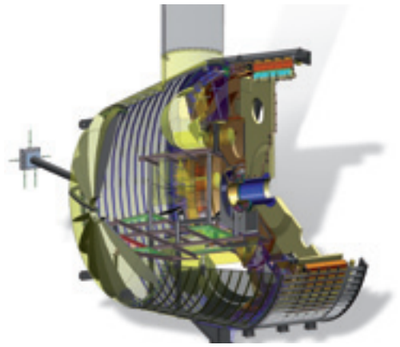
The following design criteria influence the generator's main dimensions:

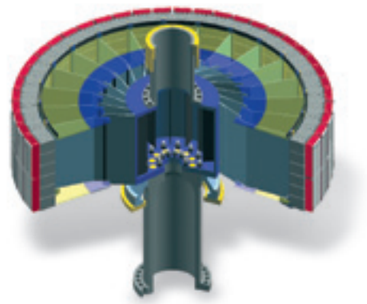
- In order to ensure a long and reliable operation it is essential that operational temperatures are aligned with the allowable limits of the materials, especially those of the winding with respect of the applied insulation system.
- The required moment of inertia must be provided within the given stator bore dimensions:
  - to enhance the grid stability and improve the LVRT (Low Voltage Ride Trough) characteristic
  - to increase the time until the power unit achieve the runaway speed
  - to reduce the water hammer pressure
  - to guarantee turbine regulation at shutdown
- 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 for 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

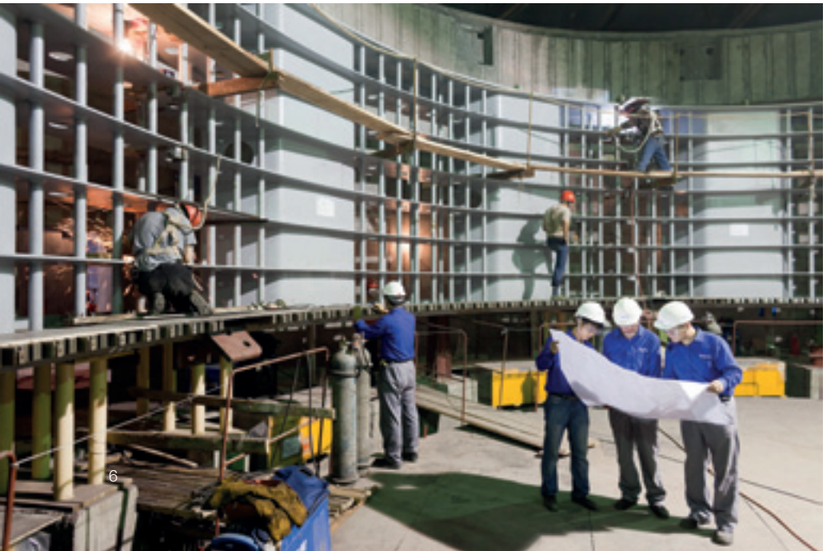
Voith has vast references in water-cooled machines and has designed the world's largest and most powerful air-cooled hydro generators, including Guri II (Venezuela) rated at 805 MVA and the 672 MVA units at Grand Coulee II (USA) as well as the world's largest and most powerful directly water-cooled units at Itaipu (Brazil/Paraguay) rated at 823.6 MVA and the 840 MVA units at Three Gorges (China). These records have been broken with the totally air-cooled generators for the Xi Luo Du power station (China) with a rated output of 855.6 MVA.

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.

3D generator models







Xi Luo Du, China

HyService and modernization – Keeps your energy flowing.

Over decades, generators have been running reliably. To ensure continuous and first class operation in the future, extensive service and maintenance will be indispensable to prevent or solve your problems effectively.

Voith offers comprehensive and tailor made first-class service and modernization solutions. A reliable service management incorporates the idea of thinking forward. Our HyService teams at Voith offer repairs, spare parts, preventive maintenance, inspections and assessments. Our focus is clear: Voith is your partner to extend the lifetime of your hydropower plant at any point of its life cycle. And we want to keep it running smoothly. As an experienced service partner we support you in any part of the plant's operation. Reliable. Experienced. Available all around the world.

Think of our modernization project of the pumped storage plant Wehr in southern Germany: by completely renewing the motor-generators, Voith increased the efficiency and especially the reliability of the machines. This included the refurbishment of the stator and rotor using modern state-of-the-art calculation methods, materials and design features. During the Bath County modernization started in 2005 we delivered six new state of the art stator windings and later six completely new rotors and each motor-generator now has a rated output of 530 MVA instead of the original 389 MVA. This helped, among other modernization measures, to reestablish

Bath County as the pumped storage power plant with the highest power output in the world. For a successful modernization such as these examples you have to consider the complete design of the plant and at the same time, you need to investigate the different options for service, refurbish and renew every single part of your generators. We at Voith develop new high quality parts and refurbish existing parts to deliver what you really need. For instance, our engineers think of individual solutions to deliver the outstanding Micalastic® insulation from our modern factories in Mississauga (Canada), Sao Paulo (Brazil) or Shanghai (China).

Get in touch with us! Contact: HyService@Voith.com

1 Manual rewinding of a 70 years old stator in a Generator Workshop of Voith Hydro, Norway.

2 Rewinding of a stator, Chilhowee, United States.

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1 Three Gorges, China
2 Itaipu, Brazil
3 Furnas, Brazil
4 Waldeck, Germany

Synchronous generators

1867 Werner von Siemens invents the direct current dynamo.

1881 Start of design and manufacturing of direct current dynamos at Siemens factory in Berlin.

1895 Kuråsfossen, Norway:
First alternating current generator for a hydropower station.

1903 Necaxa, Mexico:
World record: 6.25 MVA generator.

1938 Fengman, China:
The world's first 100 MVA generators.

1941 Grand Coulee I, USA:
The world's first 108 MVA generators.

1969 El Chocon, Argentina:
First generator with a stator bore diameter of 16 m.

1976 Guri II, Venezuela:
Most powerful air-cooled generators with 805 MVA.

1978 Itaipu, Brazil/Paraguay:
Complete mechanical design for the world's most powerful hydroelectric plant 13,300 MW). Maximum output of each unit: 823.6 MVA.

1982 Xingo, Brazil:
Design and supply of 6 generators with 555 MVA and rated speed 109.1 rpm.

1992 Grand Coulee III, USA:
New water-cooled stators for the largest hydroelectric generators in the world to date, rated 826 MVA per unit with an outside diameter of 23 m.

1997 Three Gorges, China:
Design and supply of generators and electrical equipment for the largest hydroelectric power plant in the world with an ultimate total capacity of more than 22,500 MW.

1998 Lajeado, Brazil:
Design and supply of 5 generators with 190 MVA and rated speed 100 rpm.

1999 Baspa II, India:
Design and supply of 2 generators with 122.1 MVA and rated speed 375 rpm.

1999 Cana Brava, Brazil:
Design and supply of 3 generators with 163.4 MVA and rated speed 90 rpm.

2002 Irape, Brazil:
Design and supply of 3 generators with 127 MVA and rated speed 300 rpm.

2002 Peixe Angical, Brazil:
Design and supply of 3 generators with 175 MVA and rated speed 85.7 rpm.

2003 Omkareshwar, India:
Design and supply of 8 generators with 80 MVA and rated speed 107.1 rpm.

2005 Yeywa, Myanmar:
Design and supply of 4 generators with 230 MVA and rated speed 142.8 rpm.

2005 Gilgel Gibe II, Ethiopia:
Design and supply of 4 generators with 125 MVA and rated speed 333 rpm.

2005 El Platanal, Peru:
Design and supply of 2 generators with 120 MVA and rated speed 450 rpm.

2006 Holtwood, USA:
Design and supply of 2 generators with 64.1 MVA and rated speed 85.7 rpm.

2006 Mazar, Ecuador:
Design and supply of 2 generators with 100 MVA and rated speed 257.1 rpm.

2006 Revelstoke, Canada:
Design and supply of 1 generator with 532 MVA and rated speed 112.5 rpm.

2007 Eastmain 1A, Canada:
Design and supply of 3 generators with 285 MVA and rated speed 100 rpm.

2007 Karcham Wangto, India:
Design and supply of 4 generators with 340 MVA and rated speed 214.3 rpm.

2007 Svartisen, Norway:
Design and supply of 1 generator with 320 MVA and rated speed 375 rpm.

2008 Long Kai Kou, China:
Design and supply of 5 generators with 400 MVA and rated speed 83.3 rpm

2008 Xi Luo Du, China:
Design and supply of three totally air-cooled 855.6 MVA generators. Voith most powerful generator at the time.

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1 Burdahals, Iceland
2 Cambambe II; Angola

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1 Santo Antonio, Brazil
2 Ohio River, USA

Synchronous generators

2008 Akköy II, Turkey:
Design and supply of air-cooled generators with rated speed of 750 rpm and a rated output of 135 MVA.

2009 San Esteban II, Spain:
Design and supply of 1 generator with 210 MVA and rated speed 166.7 rpm.

2010 Waneta, Canada:
Design and supply of 2 generators with 186.1 MVA and rated speed 112.5 rpm.

2010 Embretsfoss IV, Norway:
Design and supply of 1 generator with 56 MVA and rated speed 93.8 rpm.

2010 Ferreira Gomez, Brazil:
Design and supply of 3 generators with 94 MVA and rated speed 90 rpm.

2011 Budarhals, Iceland:
Design and supply of 2 generators with 45 MVA and rated speed 166.7 rpm.

2011 Teles Pires, Brazil:
Design and supply of 5 generators with 404.45 MVA and rated speed 75 rpm.

2011 Belo Monte, Brazil:
Design and supply of 4 generators with 679 MVA and rated speed 90 rpm.

2012 Las Lajas, Brazil:
Design and supply of 2 generators with 146 MVA and rated speed 300 rpm.

2012 Alfalfal II, Chile:
Design and supply of 2 generators with 145.2 MVA and rated speed 600 rpm.

2013 Cambambe II, Angola:
Design and supply of 4 generators with 195.5 MVA and rated speed 187.5 rpm.

2013 Great Millenium, Ethiopia:
Design and supply of 4 generators with 417 MVA and rated speed 125 rpm.

2014 Tarbela IV, Pakistan:
Design and supply of 3 generators with 522 MVA and rated speed 107.14 rpm.

2014 Keeyask, Canada:
Design and supply of 7 generators with 117 MVA and rated speed 69.23 rpm.

Bulb Generators

1973 Iffezheim, Germany:
Design and supply of 4 generators with 29 MVA and rated speed 100 rpm.

1988 Oberaudorf-Ebbs, Austria:
Design and supply of 2 generators with 35 MVA and rated speed 93.8 rpm.

1993 Bai Long Tan, China:
Design and supply of 6 generators with 33.68 MVA.

1994 Chasma, Pakistan:
Design and supply of 8 generators with 26 MVA and rated speed 85.7 rpm.

2007 Baguari, Brazil:
Design and supply of 2 generators with 39 MVA and rated speed 128.6 rpm.

2008 Santo Antonio, Brazil:
Design and supply of the world's most powerful bulb generators at the time with a rated output of 82.25 MVA.

2008 Willow Island, USA:
Design and supply of 2 generators with 23.72 MVA and rated speed 58.1 rpm.

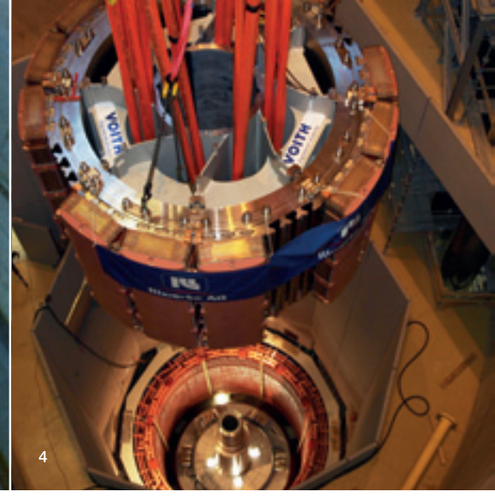
2008 Smithland, USA:
Design and supply of 3 generators with 29.9 MVA and rated speed 60 rpm.

2008 Cannelton, USA:
Design and supply of 3 generators with 33.08 MVA and rated speed 62.1 rpm.

2009 Jirau, Brazil:
Design and supply of 4 of the world's most powerful bulb generators at the time with 83.33 MVA and rated speed 94.7 rpm.

2009 Meldahl, USA:
Design and supply of 3 generators with 40.3 MVA and rated speed 64.3 rpm.

2012 Nam Hinboun, Laos:
Design and supply of 2 generators with 16.3 MVA and rated speed 107.1 rpm.



1 Wehr, Germany
2 Raccoon Mountain, USA
3 Bhira 1, India
4 Rodund II, Austria

Motor-generators

1962 Erzhausen, Germany:
Design and supply of 2 motor-generators with 62.5 MVA and rated speed 428.6 rpm.

1964 Roenkhausen, Germany:
First reversible motor-generator unit in a German pumped storage station.

1970 Raccoon Mountain, USA:
Most powerful reversible pumped storage motor-generators in the world at the time, with four 425 MVA units and directly water-cooled stator and rotor.

1971 Wehr, Germany:
Design and supply of 4 motor-generators with 300 MVA and rated speed 600 rpm.
World most powerfull machines with 600 rpm.
2008: Modernisation: New Stator
2010: Modernisation: New Rotor

1972 Rodund II, Austria:
Europe most powerful reversible motor-generator at the time with 310 MVA and water-cooled stator and rotor.

1973 Malta Hauptstufe, Austria:
Design and supply of 4 motor-generators with 220 MVA and rated speed 500 rpm.

1976 Bath County, USA:
Largest pumped storage reversible motor-generators in the world at the time, with six 447 MVA air-cooled units.

1976 Chongpyong, Korea:
Design and supply of 2 reversible motor-generators with 220 MVA and rated speed 450 rpm.

1979 Leitzach I, Germany:
Design and supply of 1 reversible reversible motor-generator with 60 MVA and rated speed 333.3 rpm.

1983 Palmiet, South Africa:
Design and supply of 2 reversible motor-generators with 250 MVA and rated speed 300 rpm.

1985 Herdecke, Germany:
Design and supply of 1 reversible motor-generator with 190 MVA and rated speed 250 rpm.

1992 Bhira 1, India:
Design and supply of 1 reversible motor-generator with 176.5 MVA and rated speed 500 rpm.

1994 Guangzhou II, China:
Design and supply of 4 reversible motor-generators with 380 MVA and rated speed 500 rpm. World most powerfull machines with 500 rpm.

2000 Venda Nova II, Portugal:
Design and supply of 2 reversible motor-generators with 106 MVA and rated speed 600 rpm.

2004 Zhanghewan, China:
Design and supply of 4 reversible motor-generators with 278 MVA and rated speed 333.3 rpm.

2002 Taian, China:
Design and supply of 4 reversible motor-generators with 278 MVA and rated speed 300 rpm.

2005 Bath County Modernization, USA:
New air-cooled winding, in the world most powerful reversible motor-generator with 6 x 530 MVA rated capacity.

2006 Waldeck 1, Germany:
Design and supply of 1 reversible motor-generators with 81 MVA and rated speed 500 rpm.

2008 Ingula, South Africa:
Design and supply of 4 reversible motor-generators with 373.2 MVA and rated speed 428.6 rpm.

2010 Frades II, Portugal:
Design and supply of Europe largest and powerful variable speed reversible motor-generators (DFIM) with 433 MVA and speed range from 350 rpm up to 381 rpm.

2010 Rodund II new, Austria:
Design and supply of totally air-cooled reversible motor-generator with 345 MVA and rated speed 375 rpm.

2012 Hong Ping, China:
Design and supply of 4 reversible motor-generators with 333 MVA and rated speed 500 rpm.

2014 Lam Ta Khong, Thailand:
Design and supply of 2 generators with 282 MVA and rated speed 428.6.

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