Pumping efficiency

A 100 MW converter for the Grimsel 2 pumped storage plant

HANS SCHLUNEGGER – Hydropower is one of the oldest forms of power generation and also one of the most flexible. Because water can be retained in a reservoir and released when needed, it is ideally suited for meeting demand fluctuations. When the mode is combined with pumped storage (meaning surplus electricity is stored by pumping water into the reservoir), its storage functionality can be expanded and it can furthermore be used in grid control by absorbing or generating the energy required to stabilize the grid. To operate more efficiently in pumping mode, the Grimsel 2 plant of Kraftwerke Oberhasli (KWO) – in the Bernese Oberland region of the Swiss Alps – has taken into service a 100 MW converter supplied by ABB.

Title picture
Kraftwerke Oberhasli is a complex of nine power plants located in the Bernese Oberland region of the Swiss Alps. The plants have a total generating capacity of 1,125 MW and an annual production of 2,200 GWh. The lakes have a combined inflow of 700 million m^3/year and a storage capacity of 200 million m^3.

At 100 MVA, the Grimsel 2 installation is the most powerful drive converter with DC link voltage delivered to date.

Pumped storage is used in what is called peak shaving: Energy is absorbed by pumping at times of low demand (typically at night) and the stored energy is converted back to electricity at times of peak demand. By mitigating the extreme peaks and troughs of the demand curve, pumped storage decreases reliance on other (often polluting) power sources required to cover peaks.

As well as bridging this classical day to night gap, pumped storage can also help integrate renewables: With more and more solar and wind power being fed into the grid, pumped storage can compensate for their unpredictability and variability, permitting consumers to continue using energy from renewable sources even when neither the sun is shining nor the wind blowing.

Moreover, moving beyond their strict mass-storage role, pumped storage plants also contribute towards grid control by producing or absorbing the relatively small amounts of power needed to more accurately balance supply and demand. To do this efficiently, the power needs to be regulated with high precision.

Grimsel 2

KWO's Grimsel 2 pumped storage plant in Switzerland → 1–2 has four synchronous generators → 3. Until recently, the plant's ability to regulate power depended on the starting up and shutting down of these individual units. When intermediate levels of power absorption were required, the difference could only be made up by running an additional unit in generator mode. Pumping and generating at the same time is not only an inefficient use of energy, but also wastes the plant's most valuable resource: its water.

To regulate the plant's power uptake more efficiently, KWO decided to equip one of the Grimsel 2 generators with a power-electronic drive. ABB won the order for this in 2010, with the installation being commissioned in 2013.

The converter

At 100 MVA, the installation is the most powerful drive converter with DC link voltage delivered to date → 4. It is made of two units of 50 MW, each with its own input and output transformers → 5, and is series-connected on both the generator and grid sides. Each of these converters in turn uses pairs of parallel-connected double-phase modules using IGCTs (integrated gate-commutated thyristors). The overall installation thus features 24 double-phase modules.

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The unit's power is continuously variable between 60 and 100 MW (the lower limit is defined by risk of cavitation in the pump runner).

1 Grimsel 2 pumping-storage plant

Power in turbine operation	4 × 80 MW
Power in pump operation	4 × 90 MW
Average height difference	400 m
Water flow	4 × 22 m³/s
Synchronous speed	750 rpm
Years of construction	1973-80

2 Grimsel 2: the lakes at a glance

	Name	Height above sea level when full (m)	Volume when full (106 m³)	Surface area (km²)	Greatest depth (m)
Upper reservoir	Lake Oberaar	2,303	58	1.47	90
Lower reservoir	Lake Grimsel	1,908	101	2.63	100

3 The Grimsel 2 plant has four synchronous generators.

4 The 100 MW converter

Starting

In turbine operation and in unregulated pumping mode, the machine set is started up with the turbine → 6. The block transformer is magnetized by the generator and connected to the 220 kV level after reaching synchronization conditions. In regulated pumping mode, the block transformer and the two line-side converter transformers would have to be switched in directly, thereby causing very high inrush current peaks. To avoid this, the frequency converter DC link is energized by the start-up transformer through the converter diodes on the motor side. The transformers are then magnetized by the line-side converter and afterwards synchronized. The entire starting procedure takes only about 10 s, after which the machine is accelerated by the converter to 600 rpm with the watered pump operating against the closed spherical valve → 6d. After opening the spherical valve, the speed is adjusted to approximately 690 rpm according to the minimum power required by the current operating head.

Power control

The active power is either set manually or by the higher-ranking plant control system, which adjusts the output of all KWO power plants to comply with the loading schedule. The line-side regulation setpoint is added to the loading schedule setpoint. The converter power and speed control are configured in cascade, the active power being limited by the current pumping head and the maximum converter power capacity.

Reactive power is regulated by a voltage control loop, set either manually or by the higher-ranking 220 kV line voltage control system. Active power takes preference over reactive power.

Operating modes

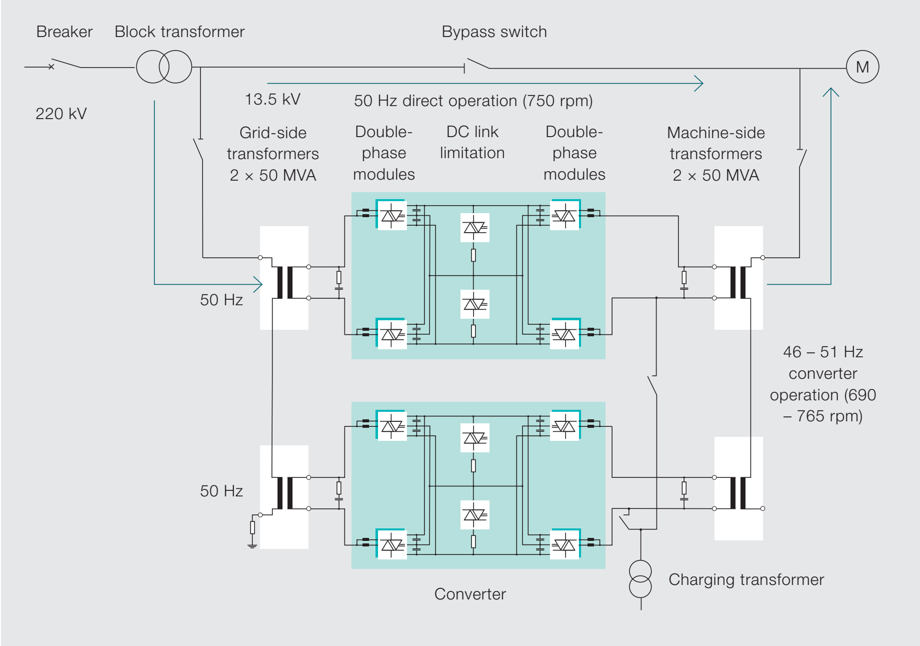
The following modes can be operated:
- Turbine
- Pumping without converter (constant rpm)
- Pumping with converter (variable rpm)
- Phase-angle correction using converter

Turbine operation with converter was not considered, because adjusting the Francis turbine speed to the relatively small head range would not compensate the converter losses.

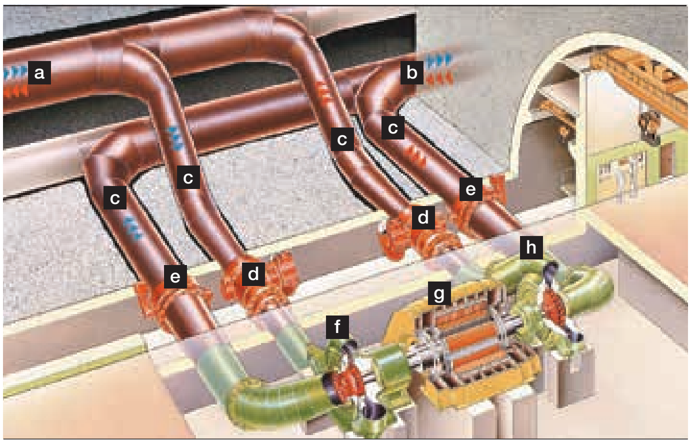
By the end of March 2014, the converter had provided 3,500 hours of controlled pumping and 850 hours of phase-synchronous condenser operation.

New pumped storage plants with pump turbines are almost exclusively equipped for variable-speed operation, using double-fed asynchronous motors according to the state of technology.

5 Schematic of the converter



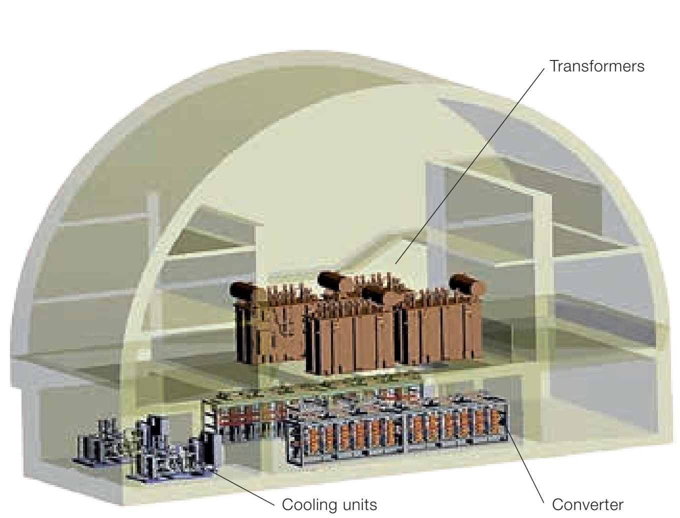
6 The turbine and its connections



a Pressure shaft to/ from Lake Oberaar
b Pressure shaft to/ from Lake Grimsel
c Connection pipes
d Spherical valve
e Throttle
f Turbine
g Pump
h Generator / motor

►►► Turbine operation
◄◄◄ Pumping operation

7 The machine-room cavern, with location of the transformers and converter.



Project execution

The converter delivery and erection schedule was adjusted to the refurbishing work taking place at the same time. This covered: overhaul of the hydraulic machinery, spherical valve and butterfly valve, renewal of the instrumentation and control systems, replacement of the turbine governor and excitation equipment, and replacement of the 220 kV switchgear.

Sufficient space was available in the existing cavern for the entire converter system ➔ 7–8. The four transformers were installed at machine room floor elevation and the converter units in the basement, where the cooling system connected to the existing plant cooling water network is also installed.

Operating experience

The installation has been in service since May 2013. By the end of March 2014 it had provided 3,500 hours of controlled pumping and 850 hours of phase-synchronous condenser operation ➔ 9.

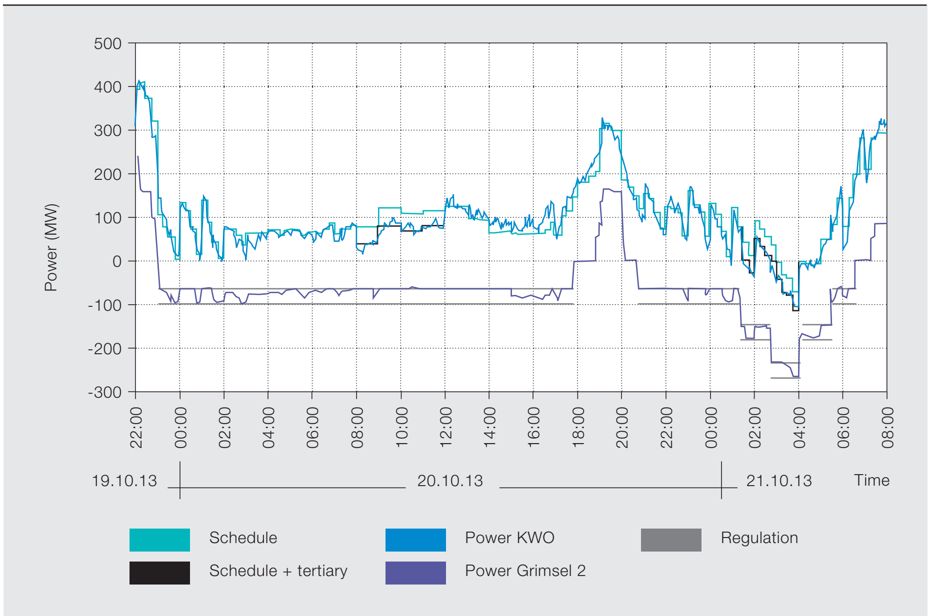
Looking ahead

New pumped storage plants with pump turbines are almost exclusively equipped for variable-speed operation, using double-fed asynchronous motors according to the state of technology. There are serious drawbacks to this type of motor, however: The complex rotor is subject to

8 The 100 MW converter could be accommodated in the basement of the machine-room cavern.

Despite progress with other storage technologies, pumped storage remains the only mature and affordable means of energy storage suitable for grid regulation.

9 The converter permits accurate regulation of the plant's power.



design limits that restrict speed increase to comply with the optimal speed of the pump-turbine. Furthermore, the starting procedure is much more complicated, sometimes even requiring pump-turbine dewatering, and compliance with Grid Code requirements is more difficult. For these reasons the trend in future will be more toward synchronous machines with full-size converters. Fitting an existing pumped storage plant with a full-size converter therefore offers an ideal way of testing this future-oriented technology in actual practice. Experience so far with the full-size converter at Grimsel 2 pumped storage plant is very promising. Despite progress with other storage technologies, pumped storage remains the only mature and affordable means of energy storage suitable for grid regulation, and thus has an important role to play in the generation landscape of tomorrow. The new converter at Lake Grimsel is a contribution to the Swiss Energy Strategy for 2050, which seeks to assure the continuity of the Swiss energy supply while increasing the use of renewables.

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Further reading

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