The generators for the Bieudron hydropower plant

The reservoir in the Val-des-Dix, Switzerland, holds 400 million cubic meters of water when full. To utilize this potential energy in an optimum way, Grande Dixence SA has expanded its hydro-electric scheme by building a new underground power plant at Bieudron. ABB is currently installing in this plant three 465-MVA synchronous generators, which will be driven by Pelton turbines. At 33.2 MVA per pole, they represent the world's highest rated high-speed hydropower generators. The machines are fully water-cooled and have only two bearings.

The new underground power plant at Bieudron holds several world records, including:

- The world's highest head: 1883 m.
- At 423 MW, the most powerful Pelton turbines anywhere.
- The highest rated (33.2 MVA per pole) high-speed hydropower generators.

Table 1 gives the main technical data of the hydropower plant.

With its new power plant, the utility operating the hydro-electric scheme, Grande Dixence SA, will optimize utilization of the valuable energy reserves contained in the 400 million cubic meters of water behind the 285-m high dam. In particular, the new plant will allow more peak-load power to be generated during the winter months. Commissioning of the plant is scheduled for the autumn of 1998.

ABB has delivered the three synchronous generators. They have been designed to generate peak-load power and are driven by three five-nozzle Pelton turbines rated at 423 MW. The three-phase, vertical-shaft generators have a rating of 465 MVA at a nominal speed of 428.6 rev/min, have fully water-cooled stators and rotors, and weigh 800 t each. The technical data of the machine are given in *Table 2*.

Main design features

The chosen design is based on field experience with similar generators as well as on measurements carried out on them.

Extensive design studies showed that it is possible for such large turbine-generator sets to be constructed with only two bearings.

A combined guide and thrust bearing, supplied by ABB Power Generation, lies above the stator, and a simple guide bearing below it. The latter bearing was delivered, together with the lower shaft end and the turbine **1**, by the consortium Sulzer Hydro / Hydro Vevey.

The thrust bearing is dimensioned to carry the full weight of all the rotating parts, together about 530 t. Designed as a multipad (Kingsbury type) bearing, it has a white-metal running surface. The pads rest on plates which are supported in the middle. The load on each pad can be measured and adjusted separately. Fitted to the outer rim of the thrust bearing is the upper guide bearing. This is a self-pumping multipad bearing, which pumps the lube oil for the combined bearing assembly through the oil/water cooler located outside of the generator pit.

Walther Howald
ABB Power Generation

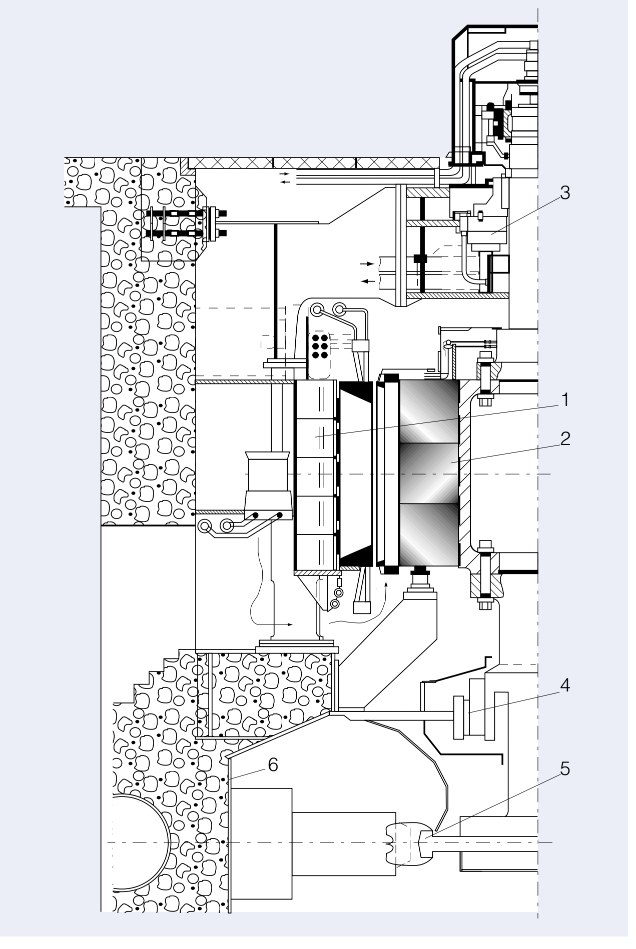
The coupling between the generator shaft and the turbine shaft is situated immediately above the lower guide bearing.

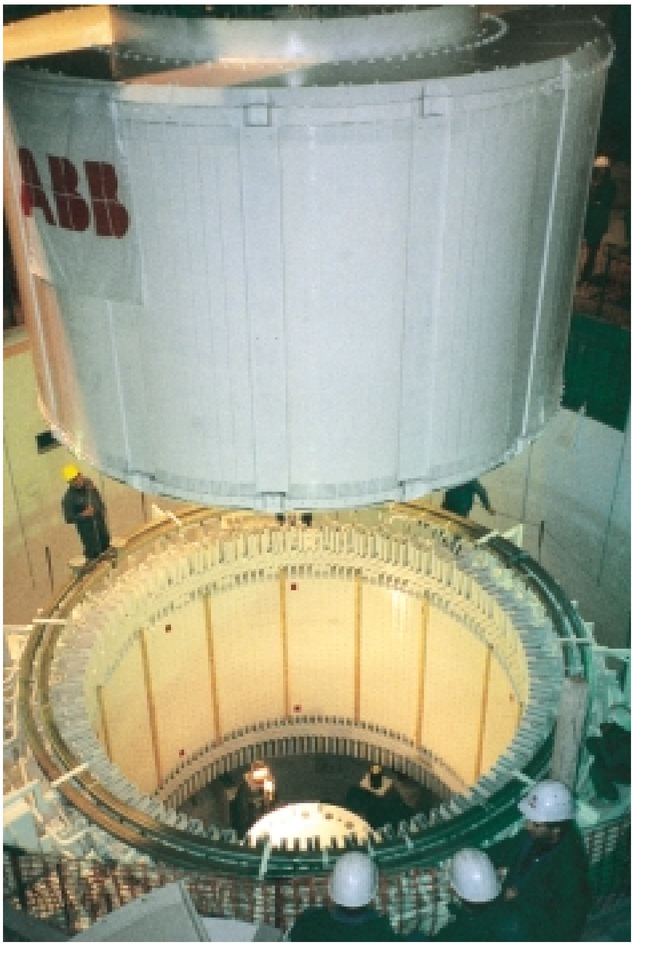
Due to the large dimensions and considerable weights involved, the generators could neither be assembled as complete units in the factory nor delivered to the power plant in the form of separate components for site assembly. The machines were therefore fully assembled in their designated positions. The limited storage space in the cavern meant that transport and assembly had to be carefully planned and organized **2**.

Stator

The stator casing, consisting of three parts, including the oblique spring elements, welded together on the site, lies directly on top of the turbine casing. After the stator casing has been welded together, the core is built up, also on-site. The 0.5-mm thick, low-loss core laminations are stacked without any separations or ventilation gaps. A laminated core built in this way has the advantage of high mechanical strength and low iron losses.

The stator winding is designed as a double-layer transposed winding, insulated with Micadur®, a vacuum impregnated epoxy resin insulation corresponding to insulation class F. To achieve a uniform potential distribution in the winding overhang at a machine voltage of 21 kV, it was necessary to protect the surface of the transposed conductors against corona discharge. The turns are cooled by deionized water flowing through hollow conductors which are also transposed. This method of cooling the stator windings has been used many times





Longitudinal section through a vertical-shaft hydropower generator for ratings of up to 500 MVA **1**

1 *Stator*
2 *Rotor*
3 *Combined guide and thrust bearing*
4 *Lower guide bearing*
5 *Pelton turbine wheel*
6 *Turbine casing*

Assembling a 465-MVA generator in the cavern of Bieudron hydropower plant. The 454-t heavy rotor has to be lowered into the stator with high precision. **2**

and is proven in hydropower generators. It is based on the very extensive experience of ABB with water-cooled stator windings in turbogenerators.

Rotor

The material stresses at runaway speed and the load on the shaft train in the event of disturbances (eg, a terminal short circuit, synchronization error or rotor double earth fault) make it necessary for the shaft train to have high flexural strength. The rotor must never be allowed to come into contact with the stator. This requirement is met by building the rotor in three parts and flanging the two shaft ends to the central body.

Four forged steel rings are shrunk onto the central body, in which 14 laminated poles are anchored by means of keyways. The field coils are shaped from extruded hollow copper conductors. During operation, deionized water flows through these conductors and cools the field coils. The damper bars are soldered into copper segments on each side of the field poles. Interconnection of the copper segments create a closed-coil damper winding.

Bearing arrangement

An important precondition for smooth running of a generator throughout the entire speed and operating range is a highly stable bearing arrangement for the complete turbine-generator set. A patented oblique arm bearing spider in the Bieudron generators ensures a constant bearing clearance during the transition from the cold to the hot state in spite of the temperature-related expansion of the arms. This arrangement also prevents additional compressive forces being exerted on the foundation due to the thermal conditions. The required rigidity is ensured by dimensioning the arm cross-sections accordingly. Although the temperature rise in the stator during operation causes a change in length, the connections to the foundation are designed such that this has no influence on the rigidity of the bearing.

Table 1:
Bieudron hydropower plant data

Plant data	
Maximum head	1883 m
Total nominal water flow	75 m^3/s
Maximum plant output	1180 MW
Duration of construction work	6 years

Technical data
- 3 spherical valves as isolating devices, diameter 1.4 m, weight 120 t
- 3 five-nozzle Pelton turbines rated at 420 MW, wheel diameter 4.65 m, wheel weight 28 t, water velocity at nozzle outlet 600 km/h
- 3 three-phase synchronous generators, rated 465 MVA at 428.6 rev/min, fully water-cooled, weight 800 t each
- 3 three-phase main transformers, rated 465 MVA, ratio 21/410 kV

The forces acting on the foundation are made up of the weight of the turbine-generator set, the forces caused by the thermal expansion during operation, the torque, and the forces and transients occurring during disturbances. Various studies were dedicated to investigating critical load cases.

Cooling

The generators are cooled exclusively by water, which enables the volume of the machine to be kept smaller. This is an important cost factor since the generators are installed in a cavern. De-ionized water flows through the stator and the rotor winding, while untreated water is used to cool the periphery of the stator core.

The cooling water for the stator winding flows from the treatment plant to a header on the upper winding overhang, from where it is distributed to the separate water circuits. Each circuit comprises four stator bars connected hydraulically in series with each other. The water exits the cooling circuits into a second header, from which it flows back via a water/water cooler to the treatment plant. The temperature of the water at the outlet of each cooling circuit is monitored.

The cooling water for the rotor winding passes via a water transmitter to the rotor, which is mounted at the top end of the shaft. The rotor windage losses and the additional losses at the pole surfaces are dissipated by motor-driven fans which blow cooling air through the generator. Afterwards, the air is recooled by six water/air heat-exchangers integrated in the flow circuit and evenly spaced in the generator pit.

Excitation and voltage regulation

Solid-state excitation equipment featuring programmable voltage regulation supplies the excitation current via sliprings to the poles. Electrographitic brushes transfer the current to the sliprings; the carbon dust is drawn off with the help of underpressure and collected in filters.

The solid-state excitation equipment consists of three single-phase transformers with rectifiers connected in parallel with the generator terminals. Each rectifier unit comprises four parallel rectifier bridges. Should one bridge fail, the remaining bridges are able to supply the required exciter current.

The voltage regulators are equipped with a device for limiting the stator current, the rotor current and the load angle. High operational reliability is therefore ensured.

Table 2:
Technical data of the hydropower generators

Rated output	465 MVA
Per pole rating	33.2 MVA
Overload, cont.	500 MVA
Rated voltage	21 kV ± 10 %
Rated current	12,784 A
Power factor	0.9/0.84
Frequency	50 Hz ± 2 %
Rated speed	428.6 rev/min
Runaway speed	800 rev/min
Moment of inertia	1,500 tm^2
Design	IM 8,415
Weight of stator	281 t
Weight of rotor	454 t
Axial force acting on thrust bearing	5,198 kN
Drive	Pelton turbine
Cooling system:	
Stator winding	Deionized water
Laminated stator core	Raw water
Rotor winding	Deionized water

Reference

[1] W. Howald, F. Stöckli: World's highest rated generators for the Bieudron hydropower plant. ABB Review 10/94, 13–19.

Author's address

Walther Howald
ABB Power Generation Ltd.
P.O. box
CH-5242 Birr
Switzerland
Telefax: +41 56 466 51 21
E-mail:
walther.howald@chkra.mail.abb.com