

## Upgrading a power station for improved efficiency

# Hydro-generator refurbishment

Since 1882, when one of the first AC hydroelectric power stations was built with a capacity of 12.5kW, the number of stations has grown very significantly not only in number but also in capacity. Today, for example, the Three Gorges power station has a capacity of 22500 MW. Many power stations were built in the first half of the 20th century, and several stations have been in operation for over 100 years. Although the dams are relatively unchanged, the efficiency improvements in turbines have resulted in increased shaft power and, therefore, increased generation output.

Hydro-generator insulation systems have a finite life and generally need to be rewound after 50 years—although some insulation systems have lasted much longer. When the generator is due to be rewound, it is an opportune time to consider increasing the rated output. Modern insulating materials, although thinner than ever, are capable of withstanding greater dielectric stress and higher operating temperatures than the materials used in the original stator and rotor windings. Figure 1 shows how a stator coil from an older machine (1950s) was redesigned to give improved performance and extended insulation life.

### Thinner insulation—increased output

As can be seen in figure 1, the thinner insulation of today's insulating systems allows more space for copper, which reduces the resistance of the stator winding. As a result, the winding will run cooler and permit a small increase in output. The higher temperature rating of today's insulation system permits higher operating temperatures and therefore increased outputs.

When a generator is upgraded, the operator needs to have design performance calculations for the new rated output of the generator. These calculations include operating curves, excitation curves, reactances, and time constants,

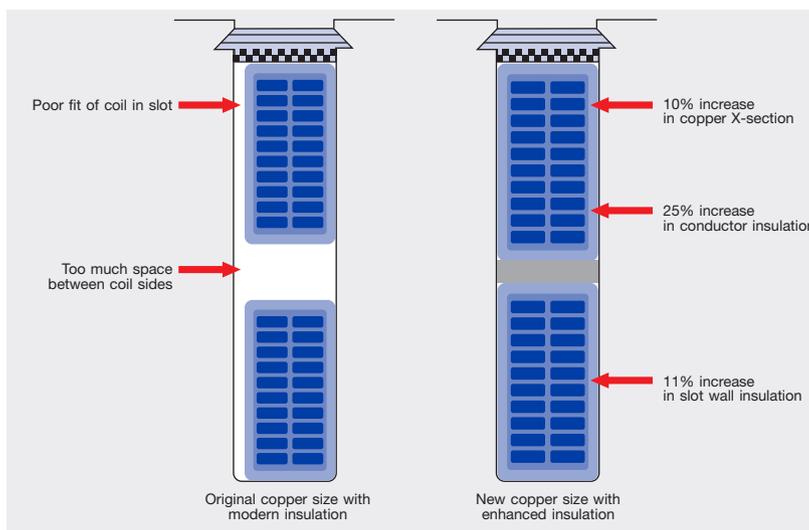
etc. Before the output can be increased, a design model needs to be produced for the original machine design and original rated output using data available from the power station operator and from site measurements. This design model has to accurately reflect the electromechanical and thermodynamic performance of the original machine when compared with original performance data and the station's operating records for temperature rise and excitation current at specific outputs.

### Improved performance

Once the design model has been produced and verified, it is used to evaluate improvements in the stator coil design and determine the temperature rises when operated at the new rated output. The design program generates the performance data required by the operator. If the refurbishment includes replacement of the stator core, there is an opportunity to use a lower-loss grade of magnetic steel than that used in the original machine construction. When changing stator core material, one must consider the increase in excitation requirements of the lower-loss grade of steel.

Occasionally, it is possible to improve performance by some adjustment of the stator slot dimensions, although it is sur-

1 Drawing of coil redesign for a 1950s generator.





2 Entrance to the underground generators in the Barron Gorge power station in Queensland, Australia.



3 Barron Gorge.

prising how good many original slot designs were, given the methods of design calculation available at the time of construction. Improvement in the control of stray losses can be achieved by changing the method of stator coil transposition in order to reduce circulating current losses, or by changing winding covers to a non-magnetic material.

Generally, any increase in generator output requires an increase in rotor excitation current. This increases the total losses within the machine with a resultant increase in stator and rotor operating temperatures.

4 Generator floor at Barron Gorge.



### Upgrade at the Barron Gorge power station

An example of a hydro-generator rewind and upgrade occurred at the Barron Gorge power station, which is operated within a World Heritage tropical forest site in Queensland, Australia 2, 3. The power station was constructed in the early 1960s and went into service in 1963. The underground station was originally constructed with two 30MW vertical 10-pole generators driven by Francis turbines.

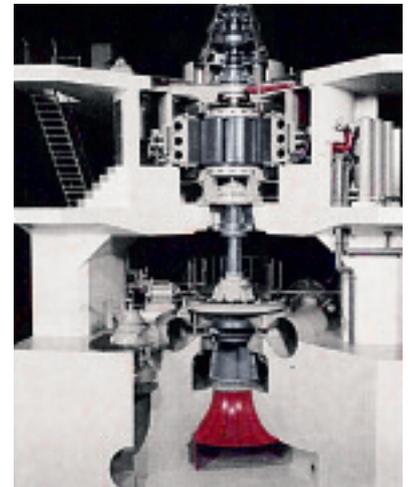
In 2009, Sulzer rewound and upgraded the first generator from 30 MW to 35 MW, and Sulzer is currently finishing the rewind and upgrade of the second generator. The original work scope was to rewind the generator stator, reinsulate the rotor, and, if necessary, rewind the exciter. When the stator winding was stripped and a stator core test conducted, deficiencies in the core were identified that necessitated the core's replacement. The customer agreed to an amended work scope and program, including a replacement core.

When the core was stripped, further deficiencies in the stator case were identified, which were rectified during the lead time for the replacement stator core. This work included the manufacture and fitting of new building dovetail bars, core bolts, and clamp plate heel system.

The stator coil redesign slightly increased the cross-sectional area of the conductor (3.12%), and the improved method of stator coil transposition reduced the stray losses. This change enabled the generator output to be increased by 16.67% within the 65 °C temperature rise limits specified in the tender requirements. The insulation system passed the IEEE 400 hr voltage endurance test. Figure 4 shows the generator floor, and figure 5 shows a station section model.

One significant change in the generator design was in the method of control of circulating current losses in the stator

5 Station section model.





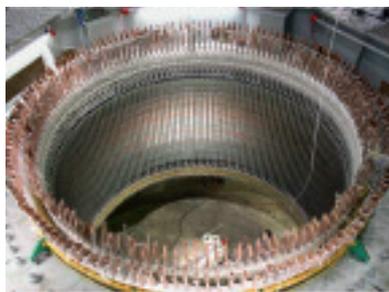
a) Original winding data recording



b) Original winding stripped



c) Rebuilding and consolidating new core



d) All new coils inserted



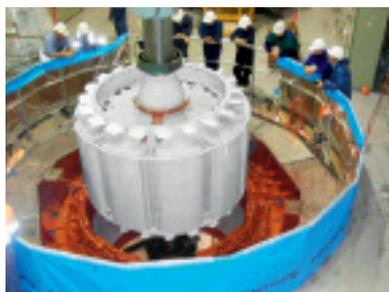
e) Stator winding connected



f) Stator winding completed



g) Reinsulated rotor



h) Generator assembly

winding. The original manufacturer's transposition consisted of two 180° twists of the top and bottom conductor stack one-quarter of the way and three-quarters of the way through each phase. The design also swapped and twisted the top and bottom halves of the conductor stack halfway through the phase. The new transposition system had double top-top or bottom-bottom strand transpositions at all coil connections.

### 10% reduction in losses

The replacement core lamination segments were manufactured from a grade of magnetic steel that provides a 10% reduction in losses over the material used in the original machine construction. The rotor field coils were stripped and reinsulated with Class F insulating materials, as was the DC exciter. The DC exciter was redesigned to enable an increase in field forcing from 150% to 200%.

6] Stages of the rewind.

The site rewind was managed by our labour from UK and Australia. The Sulzer Dowding & Mills branch in Brendale, Brisbane, Australia, rewound the field coils and exciter. The location of the site within this unique World Heritage tropical forest site introduced some additional environmental challenges for the project management.

### Enhanced generator efficiency

The stages of the rewind can be seen in figure 6] a-h. It was possible to enhance the efficiency of the generator from 97.99% before the rewind to 98.09% after the rewind. The losses for the generator before and after rewind are shown in figure 7].

The first rewind was completed within the revised program as agreed with the customer. The second rewind is currently due to be completed four weeks ahead of schedule. The tests at the completion of the first rewind met the customer's requirements, and, during the heavy rains earlier this year, the rewind generator ran continuously at maximum output.

Generator	Original	Upgraded
MVA	33.33	39.00
MW	30.00	35.00
<b>Fixed losses</b>	<b>kW</b>	<b>kW</b>
Friction, windage, and iron losses	361.00	361.00
NL excitation losses	24.70	24.70
<b>Variable losses</b>		
FL excitation losses	60.30	78.10
FL stator and stray losses	173.00	219.70
Total losses	616.00	683.50
Efficiency	97.99	98.09
Stator temperature rise	46 °C	53 °C
Rotor temperature rise	43 °C	55 °C

7] Losses for the generator before and after the rewind.

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