Retrofit packages for 200-MW turbogenerators

ABB has developed new retrofit solutions especially for 200-MW turbogenerators of non-ABB design. They extend lifetime by an extra 20 to 30 years, allow base-load machines to be used for peak-load duty, increase the reliability and availability of the generators and auxiliaries, and reduce maintenance and repair costs. Use of state-of-the-art technology also allows a 15 percent increase in power output to approximately 230 MW. Customers further benefit from a short payback time and higher efficiency, the latter translating into more environmentally friendly power generation. Numerous retrofits carried out recently on turbogenerators in Poland underscore the improvements that are achieved with the new packages.

As a rule, normal maintenance and repairs are not enough to ensure constant high availability and low-cost operation for modern-day power plants over an extended period of time. Besides installing new equipment, many utilities are therefore also investing in retrofit and rehabilitation schemes designed to make their existing power plants economical and competitive again. This option enables power plant operators to increase their competitive edge and at the same time utilize their invested capital to the fullest.

Due to its multi-domestic approach to business, ABB is often faced with having to service and retrofit power plants of non-ABB design. Thus, the worldwide operations of its business units has placed ABB in the unique position of knowing many non-ABB technologies in detail. The same multi-domestic approach also allows solutions to be tailored exactly to local circumstances and a large share of the manufacturing work to be carried out locally.

ABB therefore has a long tradition of retrofitting both its own and non-ABB power plant components [1–7]. Innovative packages have been developed especially for retrofitting power generation equipment in Eastern Europe and the former Soviet Union. In the following, a look is taken at ABB retrofit solutions for 200-MW turbogenerators of non-ABB design [8].

Development goals

The goals behind the development of the new retrofit packages were to extend the lifetime and improve the reliability and performance of the turbogenerators. Problems related to aging, system quality and design were to be eliminated. Moreover, the new packages should increase the rated output of the retrofitted turbogenerators by a substantial amount.

By adopting state-of-the-art ABB technology that includes class F insulation, high-grade materials and advanced design improvements, it was intended to:

- Extend operation by an extra 20 to 30 years
- Convert base-load units for peak-load duty
- Increase the reliability and availability of the generators and auxiliaries
- Reduce maintenance and repair costs
- Increase output levels to at least 230 MW (ie, raise the performance by an additional 15 percent)

The retrofit solutions were developed in the form of different packages to offer maximum flexibility. Thus, they enable ABB to satisfy the requirements of customers with different technical problems as well as varying financial resources. Each package solves a specific problem and can be used independently of any others that are ordered.

The modularized packages target specific retrofit areas:

- Modernization of the stator
- Modernization of the rotor
- Brushgear with forced ventilation
- New radial oil seals
- Separate seal oil system
- Temperature control of hydrogen and stator cooling water

Together, the solutions set out above cover the performance and technology of the complete turbogenerator. An example of a generator retrofit involving all of the new packages is unit 5 at the Dolna Odra power plant in Poland **1**.

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Modernization of the stator

End winding

A typical drawback of the original design of the retrofitted generators was the rigid fixing of the stator winding to the

brackets. This meant that all of the axial forces occurring during operation, and especially during load changes, were directed towards the end winding. As a result, thermal elongation and pull-out of the stator core sometimes occurred, loosening the bars and core end.

The new end winding fitted by ABB features axially flexible supports **2**. These move independently of the bracket and pressplate, thereby eliminating the earlier axial expansion problems.

Stator winding

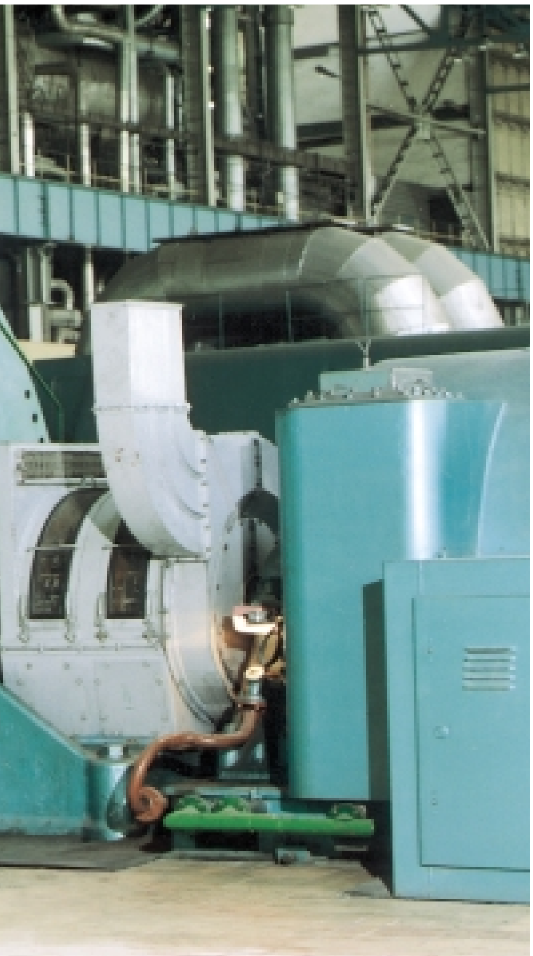
In the course of modernizing the stator, not only the end winding but also the stator bars were completely renewed. The new bars are insulated with ABB's advanced MICADUR® class F insulation, which will also enhance the lifetime of the retrofitted stator. Improved reliability and optimization of the long-term behaviour are further achieved through individual measurement of the temperature of the high-purity cooling water for each bar. This guarantees the best possible monitoring of the cooling system.

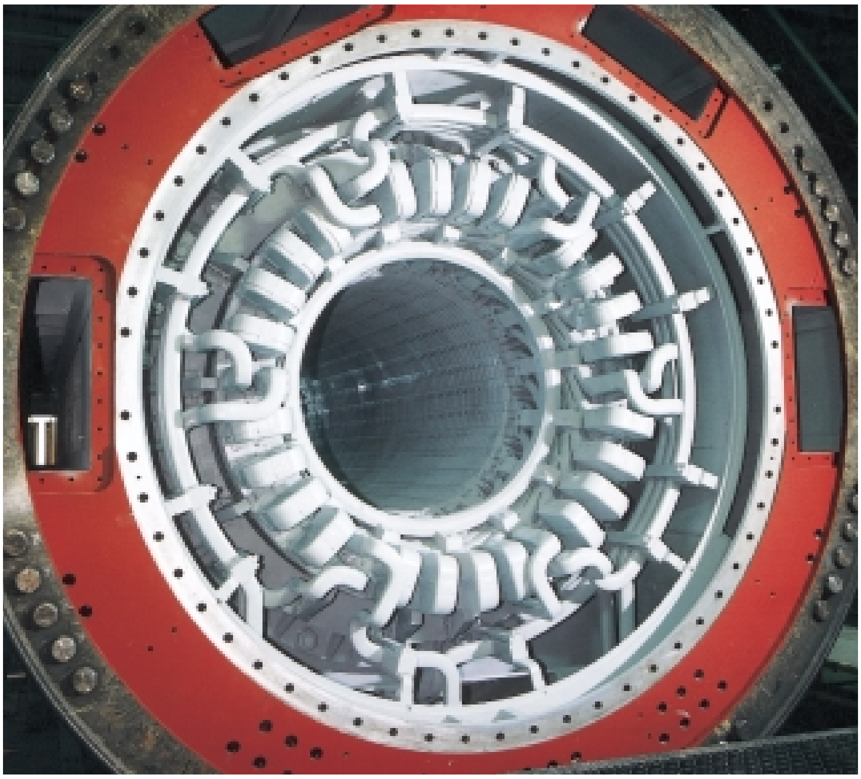
ABB water chamber

A feature that was common to all of the turbogenerator types that were retrofitted in Poland was the design of the water chambers, which did not allow separate electrical connections. The thermal elongation experienced by the stator as a result caused thermal and vibrational stressing of several critical components, eventually leading to damage to the end-winding system. The new design completely separates the electrical connections from the water chamber. The mechanically strong structure is firmly fixed to the bars and is easy to fit. The water chambers themselves are of proven ABB design and made of high-quality stainless steel. Besides preventing hydrogen or water leakage, this solution also allows separate opening and checking of the water circuit **3**. System maintenance is much easier with the new design.

Double tapered wedges

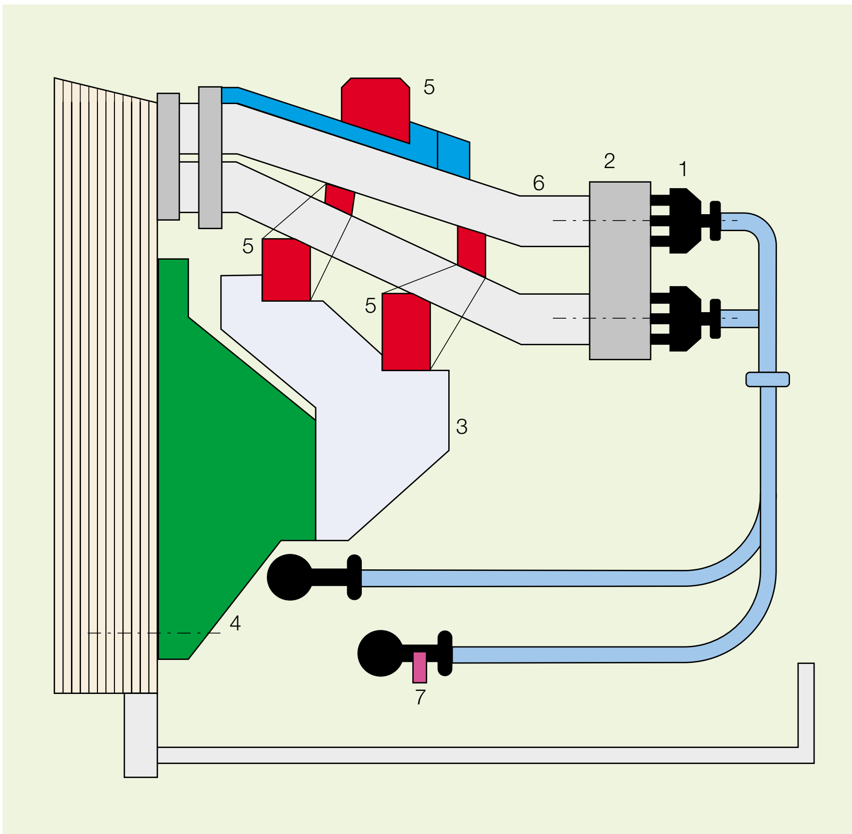
Special attention was paid to the wedges and the processes used to manufacture them. The bar support in the stator slots has to ensure that two main requirements are met: the clamping force has to be greater than the maximum force that can occur in operation, and this clamping





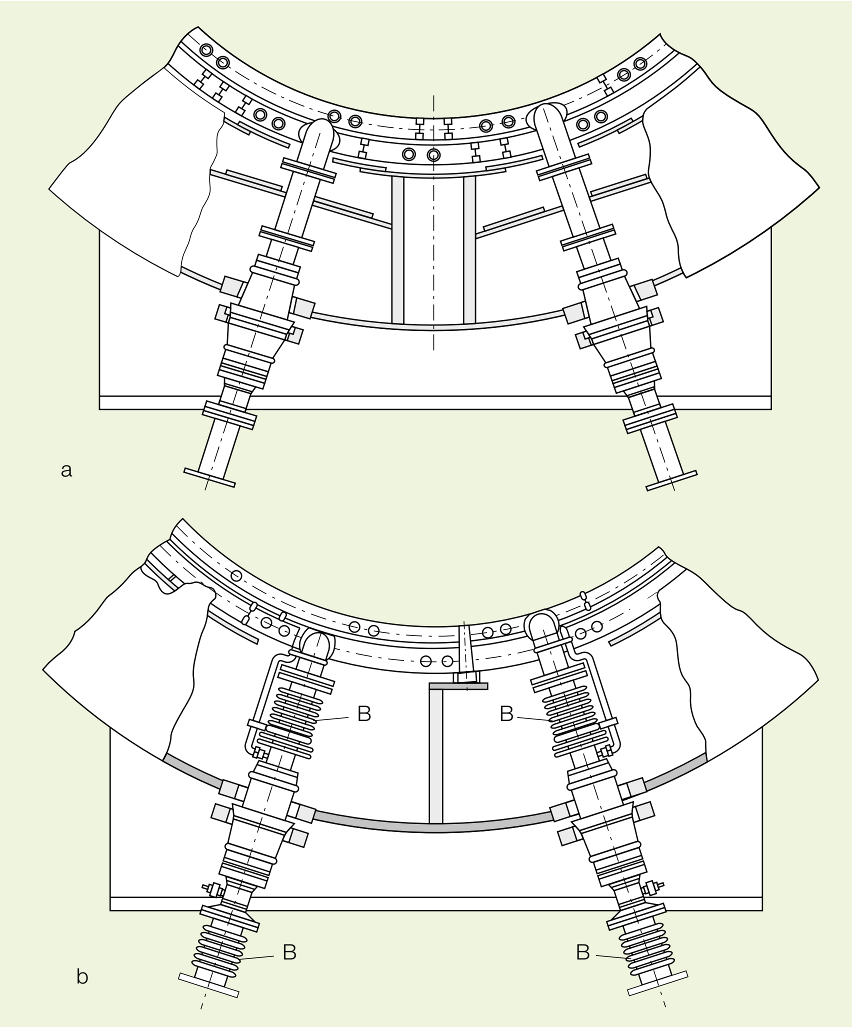
Modernization of the stator. Axially flexible suspension of the end winding eliminates problems caused by axial movement due to thermal elongation. **2**

No. 5 unit at Dolna Odra power plant in Poland. The turbogenerator was successfully modernized using the full scope of ABB's newly developed retrofit packages for 200-MW units. **1**



Changes made to the end winding. The electrical connections between the stator bars are separated from the water connections. The end winding can shift without pulling the pressplate off the core. Also, the temperature of each bar is controlled. **3**

1 Water chamber, ABB design
2 Electrical connections
3 Bracket
4 Pressplate
5 End-winding fastenings
6 Stator bars with MICADUR® insulation
7 Temperature detector



Water terminal connections in the original machines (a) and the new design (b). Rigid connections to the casing, which do not allow for thermal static or dynamic stress, are replaced by stainless steel bellows (B) which make allowance for all of the forces acting on the terminals. **4**

force has to remain constant. To keep the clamping force constant, a special wedging method was used. This and the process used to manufacture the wedges eliminate any later settling of the slot filling due to surface unevenness. The required high clamping force and elasticity are ensured by the use of short double tapered wedges.

Flexible suspension of the stator core

Experience has shown that rigidly fixed stator cores tend to vibrate [9]. These vibrations may even be transmitted to the casing, possibly causing damage to the key bars. In the original design of the generators retrofitted to date, the key bars were welded to the casing. To completely eliminate, or at least minimize such vibrations, which are known to have occurred in practice, special procedures were adopted. In the new design, a flexible suspension dampens the vibrations to a very high degree. Additionally, it was possible to increase the core density by vibrating the core magnetically during its manufacture and during the retrofit procedure. This and the use of reinforced pressplates and press fingers, which are made of a special material, increased the tightness of the core, thereby suppressing the vibrations to a remarkable degree.

Axial compensators are integrated in the water terminal connections

Another source of hydrogen and water leakage were the rigid connections to the terminals. This problem could be overcome by introducing axial compensators **4**. By reducing the thermal, static and dynamic forces, these compensators guarantee optimum tightness.

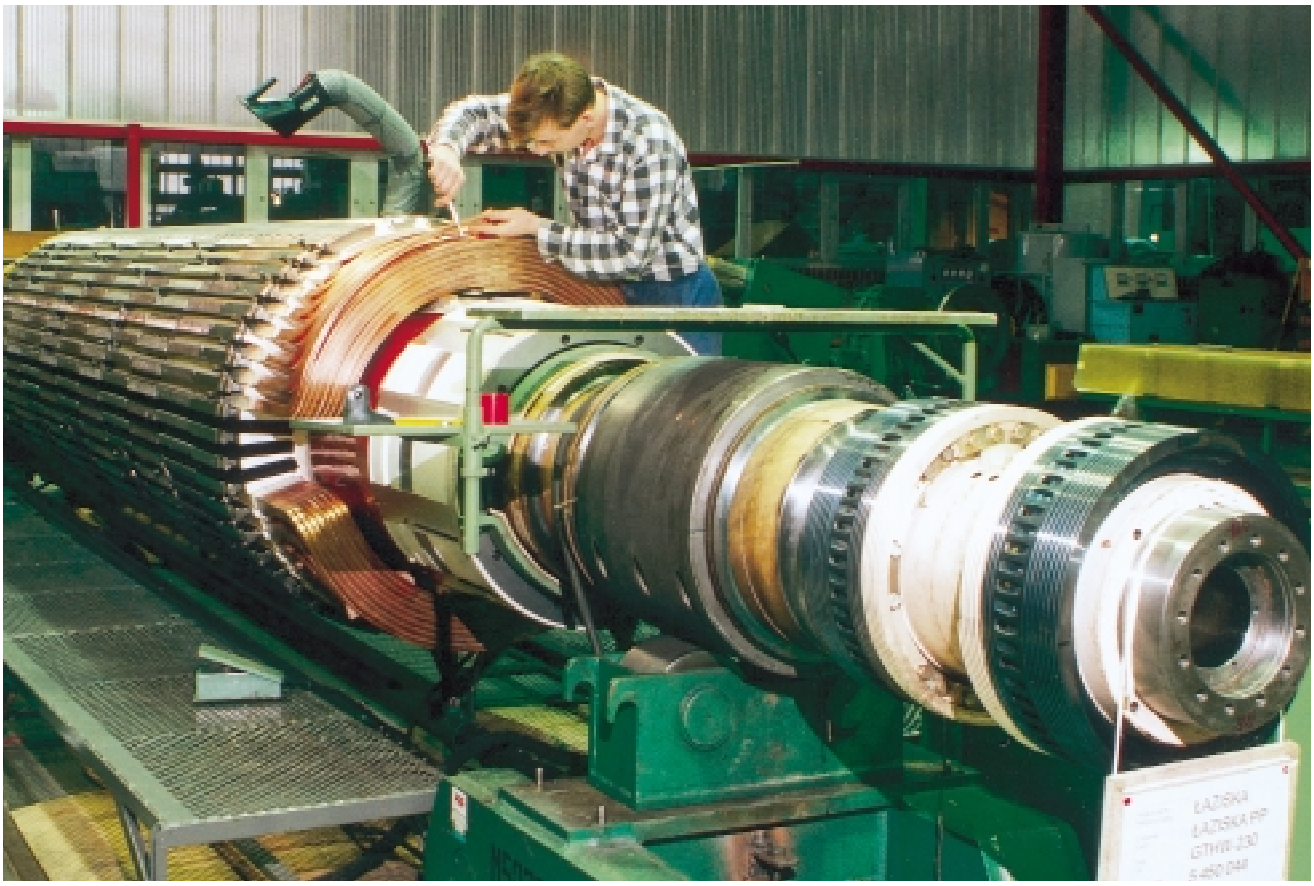
Together, all of the measures described above substantially reduce the danger of component damage and extreme leakage of hydrogen or water. Their combined effect is to increase the stator life by another 20 to 30 years.

Higher power output

Other measures that were integrated enhance the power output of the turbogenerators. For example, the magnetic losses were reduced by increasing the stepping of the end core laminations to achieve an optimum profile. Other measures designed to increase the power output were introduced in connection with the retrofitting of the rotor.

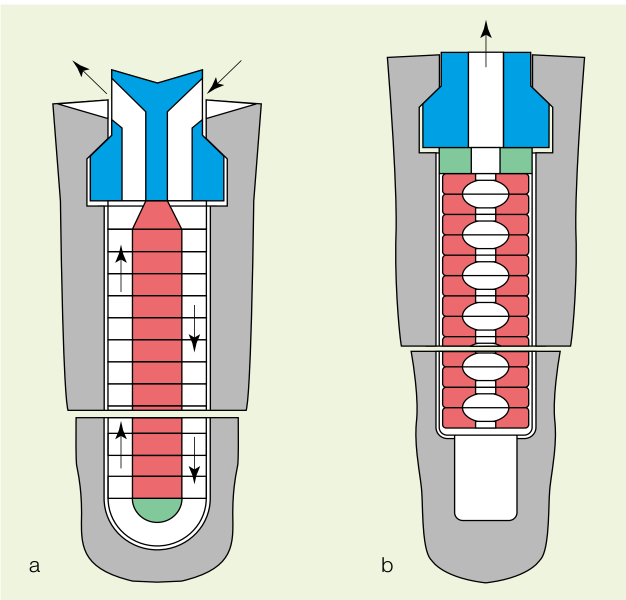
Modernization of the rotor

The main objective of modernizing the rotor was to reduce the field winding temperature and so enable the power output of the turbogenerator to be raised to 230 MW. This goal is also supported by measures taken to extend the lifetime and reliability of the rotor components **5**.



Retrofit work being carried out on a rotor for Laziska power plant (Poland) in the factory of ABB Dolmel, Wroclaw **5**

Changeover from radial (a) to axial (b) rotor cooling. In the new design (b), the inflowing cooling gas comes from the rotor end-winding area. The gas flows through the windings and leaves in the middle of the rotor. **6**



Rotor retrofit. The shape of the rotor slots has been changed to avoid local overheating. **7**

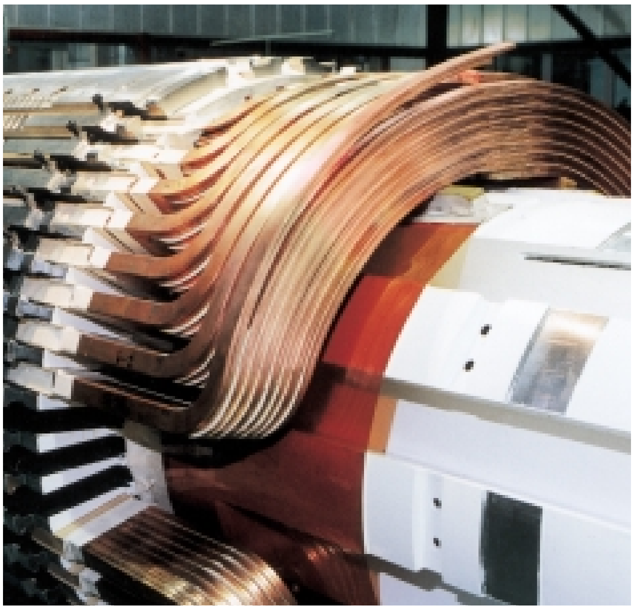


Table 1:
Comparison of data for the old and new rotor designs

	Previous design	New design
Rated output	200 MW	230 MW
Cooling water temperature	33˚C	33˚C
Field current	2,660 A	2,570 A
Maximum field winding temperature*	115˚C	110˚C
Actual field winding temperature	approx. 115˚C	$<$100˚C

* IEC 34 Standard

Windings modified for axial cooling

To achieve the required increase in power output, the radial cooling of the windings was replaced by axial cooling plus a sub-slot. In 6a, the previous cooling-gas path can be seen on the left-hand side. Due to the way the slot entrance and exit are designed, there is a risk of local overheating of the parts in these regions. In an actual case of overheating, the insulation was found to be damaged. This no longer happens with the modernized rotor design 6b due to the very homogeneous temperature distribution along the windings. Calculations and manufacturing are both easier with the new design, which results in a lower winding temperature, a homogeneous temperature distribution and higher efficiency 7. *Table 1* compares some of the results that have been achieved.

Retaining rings

Materials research at ABB has a long tradition and has produced many successful commercial results. One typical research activity, for example, concentrated on intercrystalline corrosion-proof materials, which offer very high resistance to stress corrosion cracking [10, 11]. These materials are not as sensitive to moisture as the older materials are.

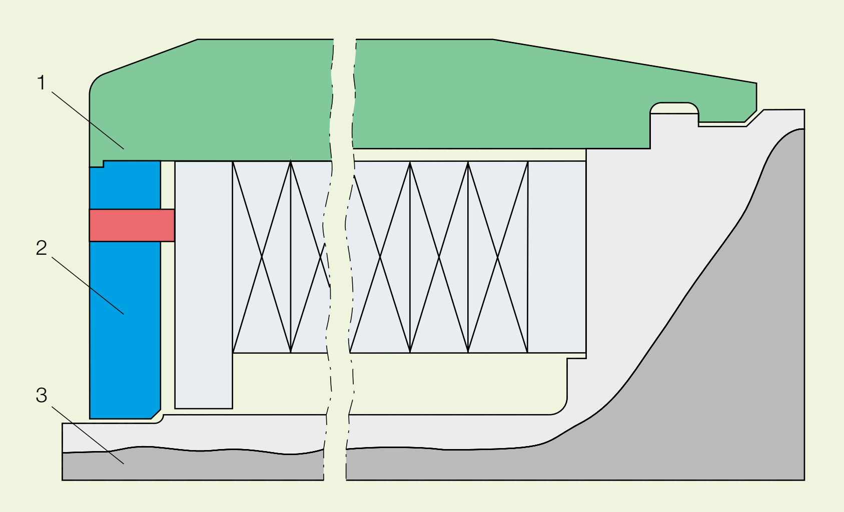
ABB uses advanced tools to evaluate different shapes and designs for the retaining rings. It has also been established that the modern materials ABB uses for the retaining rings in its new turbogenerators are equally suitable for the retaining rings used for non-ABB turbogenerator retrofits. The design is changed to increase the lifetime of the parts 8. Free axial expansion of the end winding is possible due to the use of a bayonet-type fixing method, which also makes assembly easier. Whereas double shrink seats are subject to changes due to alternating bending stress, the so-called 'flying' retaining ring allows free axial expansion without the risk of damage that existed previously.

Rotor leads

Another source of hydrogen leakage with the potential to cause an explosion could be eliminated by modernizing the rotor leads. In the previous technology, two bolts with conical threads were used to connect the leads to the slipring. Damage due to deformation was often caused in the past by the use of different materials, including rubber, having different expansion properties. The new design makes use of advanced thermal insulation materials which allow thermal expansion without the risk of hydrogen leakage.

Sliprings

The sliprings were also modernized. This was to eliminate their tendency to become oval, and thus reduce the danger of run-out. The use of new materials and processing methods has significantly improved the performance of the brushes.



Retrofitted retaining ring with bayonet fixing. The retaining ring is made of intercrystalline corrosion-proof material. **8**

1 *Retaining ring*
2 *Centering ring*
3 *Rotor body*

Brushgear with forced ventilation. The new casing design improves the cooling of the brushgear and reduces noise dramatically. **9**

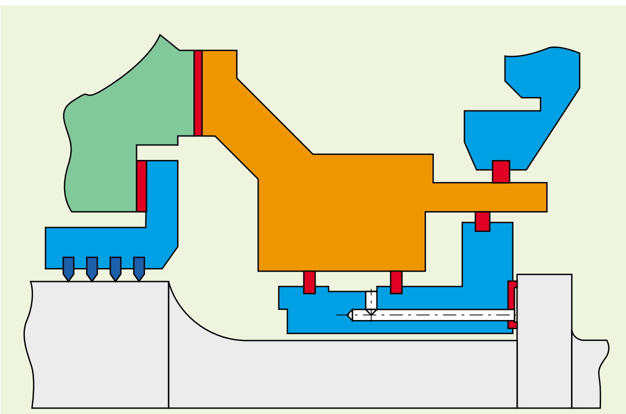
The new design increases the efficiency of the carbon-dust cleaning and lengthens the lifetime of the brushes. Improvements were not only achieved by using different lead seals but also by making changes to the connections between the rotor lead bar and the lead bolts as well as to the method of insulation and the sliprings themselves.

Brushgear with forced ventilation

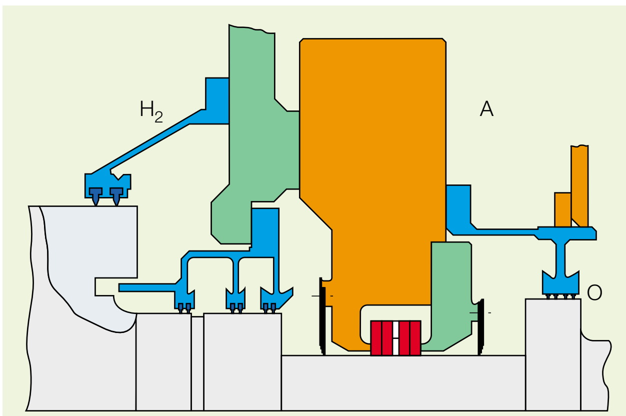
The absence of casings meant that it was especially difficult to achieve efficient ventilation with the older brushgear systems. The newly developed brushgear is an encapsulated system of the 'open ventilation' type, fitted with an additional fan for forced ventilation **9**. Lower temperatures for the brushgear translate into a considerable increase in lifetime. The new system is also designed for ease of maintenance, whereby the running costs of the installation are reduced.

Oil seal system before and after retrofitting. With the previous axial rotor shaft seals* (a) *there is a risk of leakage due to the thermal expansion that occurs during load changes. **10**
New radial shaft seals (b) ensure tightness even in cases of sudden axial movement and thermal elongation of the rotor.

H_2 *Hydrogen* A *Air* O *Lubrication oil*

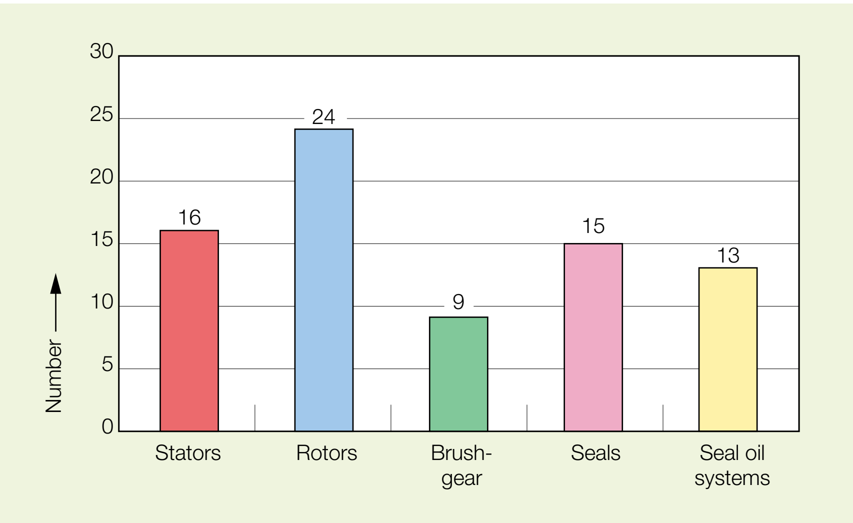


a



b

New seal oil unit installed at Dolna Oldra power plant in Poland. The system comprises a single unit, and all accessories are located in one place. Connections to the generator are direct. **11**



New radial oil seals and a separate oil system

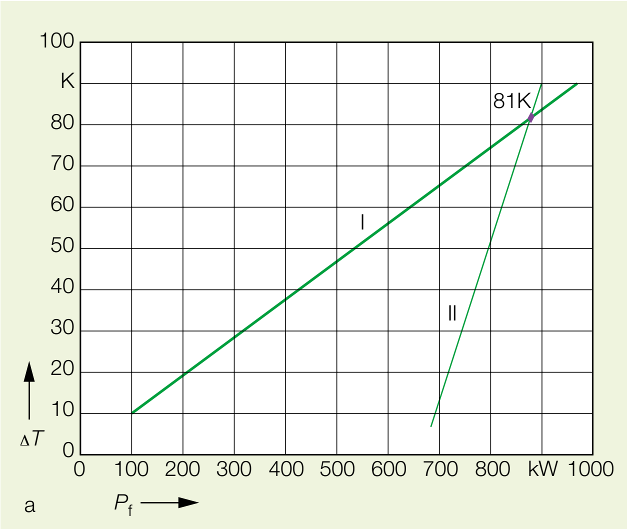
The oil seals in the retrofitted machines were all of the axial type. The disadvantage of seals of this kind are that they can be damaged by axial expansion of the rotor, possibly resulting in loss of hydrogen and even leakage of oil into the turbogenerator. The newly developed system features proven ABB standard radial seals and a single-circuit seal oil system. The reliability, safety and performance of this system, which separates the seal oil from the lubrication oil, have proved to be excellent **10**, **11**. The new ABB seal oil system is based on vacuum degassing and guarantees very high purity for the oil. This in turn improves the cooling of the hydrogen, which increases the efficiency of the turbogenerator.

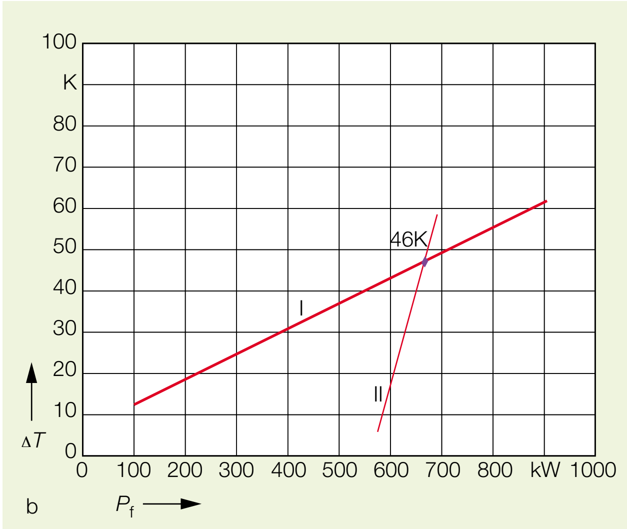
Temperature control of the hydrogen and stator cooling-water

The temperature of both the cold gas and the high-purity water should remain as steady as possible during operation of the turbogenerator. An improved gas cooling-water system, in which the recirculation of the cooling water is automatically controlled, allows the cold-gas temperature to be kept at a constant value.

Whereas in the previous designs the temperature of the high-purity water flowing through the stator bars was monitored but not controlled, the new design allows temperature control. This is necessary, since a variation in the temperature of the stator bars could result in damage or degradation of the main insulation due to thermal expansion. In the new, improved design, the temperature

Retrofit projects carried out on 200-MW turbogenerators in Poland **12**





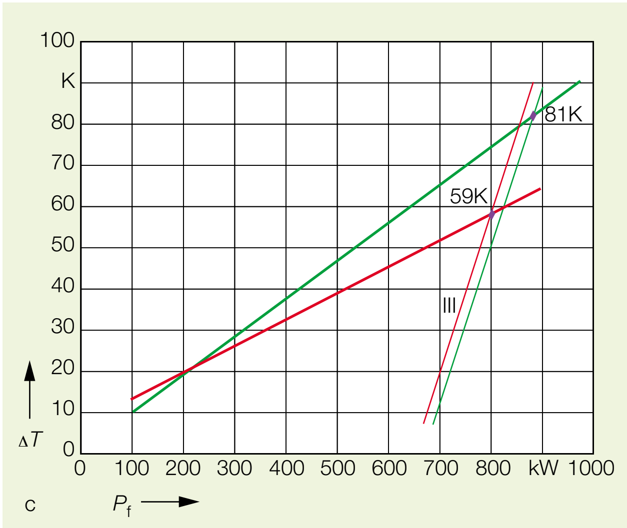
13

Measured temperature rise as a function of the field winding losses.
The temperature rise of 59 K after modernization, which increased the unit's power output to 230 MW, is lower than it was before (81 K) at 200 MW.

a *Before modernization*
b *After modernization*
c *After modernization, with increased power under same operating conditions (230 MW instead of 200 MW)*

ΔT *Temperature rise*
P_f *Field winding losses in kW*

I *Temperature rise for different field currents*
II *Field losses at 200 MW*
III *Field losses at 230 MW, after modernization*



of the water is monitored precisely and held constant by a special temperature control valve.

These and other measures ensure that the useful life of the windings is maintained even under variable load conditions or with daily run-up of the turboset.

Field experience

The described improvements have been carried out on numerous 200-MW turbogenerators in Poland **12**. One major Polish power plant operator now has four fully modernized generators in operation **1**. Other power plant operators have ordered selected packages. The customers have expressed complete satisfaction with the new retrofit packages and the easier maintenance that they have made possible.

Measurement of the operating temperature

Measurements carried out on the original generators showed overheating of the rotor windings to be a critical design problem. The measurements performed since modernization by ABB confirm the calculations and also the expectations with regard to the winding temperature, which has been reduced below the IEC 34 limits to allow for a higher power output.

13 shows the rotor winding temperature measured in a Polish power plant before and after rehabilitation. The temperature rise measured using the resistance method is shown as a function of the rotor winding power loss. **13a** gives the graphs for the unit before modernization, while **13b** and **13c** show the results of measurements carried out since the retrofit. The thick lines give the temperature rise for different field currents. The field winding losses P_f are calculated from:

$$P_f = I_f^2 R_f$$

In the above, I_f is the field current and R_f the field winding resistance.

The steeper lines reveal the real field losses for different temperatures at a certain rated output. It can be observed that a modernized rotor fulfils the requirements of IEC 34 for class B insulation even for a power output of 230 MW (59 K, ie 11 K below the IEC limit). For an output of 200 MW the temperature of the same rotor winding is approximately 35 K lower than before modernization (46 K compared with 81 K). This ensures more acceptable conditions for the rotor insulation. The thermal elongation of the rotor winding, which could cause mechanical damage, is also reduced. The results show that the temperature rise in the rotor windings could be reduced considerably. Together, the new rotor design, class F insulation and high-grade material used for the retaining rings enable the lifetime of the rotor to be extended dramatically. It is also possible to extend the time between overhauls from 8 to 10 years without having to remove the rotor in the intervals between.

Thermal measurements carried out on the modernized stator show that for power outputs of 230 MW the temperature of the stator winding, cooled by high-purity water at 40˚C, does not exceed 90˚C. The IEC limit for stator winding temperatures for class B insulation is 120˚C. Also, the maximum temperature of the cooling water measured at the outlet of the stator bars is lower than 70˚C, a figure well below the IEC limit of 85˚C. This confirms that the modernized turbogenerator can operate with an output of 230 MW without special measures having to be taken.

Local manufacturing is possible in many countries

A full-scope retrofit for a turbogenerator takes approximately 18 weeks, including manufacturing and works assembly. Excluding the auxiliaries, the cost of modernizing an existing generator is approximately ⅓ of the price of a new unit with a comparable power output. This makes retrofitting attractive for utilities operating units of the older design. While the described retrofit is one of several possible solutions, in many cases it will be the most cost-efficient one.

All of these retrofit options are available to customers through ABB's global manufacturing network. The local manufacturing content will make such solutions more attractive to utilities. Also, it will foster closer customer relations and increase customer satisfaction due to the convenience of such collaborations.

Summarizing, it can be said that retrofitted turbogenerators in the 200-MW class achieve the same performance as new units of the same rating. The customer gets a rehabilitated machine that incorporates the latest and best technology available on the market. As a result, the lifetime of such generators is extended by an extra 20 to 30 years. In addition to the benefit of early financial payback, retrofitting and efficiency enhancement will make an important contribution towards environmentally friendly power generation in the future.

References

[1] A. Ulrich: Power Plant Service Management – a new concept for optimizing power plant performance. ABB Review 5/95, 21–27.

[2] K. Weigelt: Successful retrofit of a 970-MVA turbine-generator. ABB Review 3/88, 3–10.

[3] J. Schöninger: Power plant service – a new concept for faster retrofitting of turbogenerators. ABB Review 10/95, 23–30.

[4] T. Torsteinsrud: Faster replacement of generator stators in nuclear power plants. ABB Review 2/94, 8–12.

[5] E. Kraemer, H. Huber, B. Scarlin: Low-pressure steam turbine retrofits, ABB Review 5/96, 4–13.

[6] P. Olechnowicz, K. Czwiertnia, B. Luniewicz: Rehabilitation, retrofit and modernization of 200 MW turbine sets. Proc. PowerGen Asia '93, Singapore, 13–15 Sept 1993.

[7] G. Kosman, A. Rusin, K. Czwiertnia, B. Luniewicz, P. Dobrowolski: Steam turbine retrofits and modernization as the basis for life extension. Proc. PowerGen Europe '96, Budapest, 26–28 June 1996.

[8] T. Gajowy, W. Suchecki, B. Gellert: Successful retrofit of 200 MW turbogenerators of non-ABB design, Proc. PowerGen Asia '96, New Delhi, 3-247 to 3-259.

[9] J. Przybysz: Turbogeneratory eksploatacja i diagnostyka (Turbogenerators: operation and diagnostics). Published by WNT, Warsaw (Poland), 1991, 114–117.

[10] M. O. Speidel, G. Gabrielli, B. Scarlin: Alloy development and service reliability of retaining rings. Proc. of the Intern. Conf. on Advances in Material Technology for Fossil Power Plants, Chicago, 1987, 461–467.

[11] G. Gabrielli, K. Weigelt, B. Scarlin: Overall consideration of rotor retaining rings for reliable operation. EPRI Generator Retaining Rings Workshop, September 15–17, 1987.

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