Steam turbines retrofitted in record time

Following a decision by the Finnish government in 1993 not to build another nuclear power plant, electric utility TVO looked into other ways of increasing production capacity to meet growing power demand. Modernizing power plants to improve the efficiency of existing components and achieve higher output is one of the most economical options open to utilities. ABB recently replaced the inner blocks of the low-pressure steam turbines in the 735-MW Olkiluoto 1 nuclear power plant in Finland after 17 years of trouble-free operation. As a result of the retrofit, the plant output was increased by almost 5 percent, or 36 MW. Close cooperation between the customer and supplier as well as between the different ABB companies involved enabled the project to be completed in record time.

Almost 20 percent of the total electricity produced in Finland is generated in the two nuclear power plants Olkiluoto 1 and 2 **1** of Teollisuuden Voima Oy (TVO). Both of the units, which have been in operation for 17 years, are world-class performers with capacity factors as high as 94 percent. Base-load operation with only very short overhauls during fuel replacement characterize the operation of the two units.

Feasibility studies

Based on initial discussions with the customer in 1993, it was decided to carry out a preliminary study to identify the potential for improving the plant output. A modified heat balance with the current performance of the steam cycle, including all relevant changes to the major components and the current operating conditions, was established in close cooperation with the customer. In parallel with this, the consequences for the steam cycle of an increased reactor load were identified. The target for the preliminary study was to determine the limitations applying to the main components in terms of the:

- Maximum admissible load
- Potential for increasing efficiency
- Need for modernization
- Remaining lifetime

The study showed that the low-pressure (LP) turbines **2** offered the greatest potential for an improvement in steam cycle efficiency as well as the best cost-benefit ratio.

There are several reasons for the large potential for reducing losses in the existing low-pressure turbines by applying modern technology:

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- The LP steam turbines installed in Olkiluoto were developed in the 1960s. At the time, only simplified methods of calculation were available with which to optimize the complex transonic flow in the last turbine stages. Today, design engineers use three-dimensional CFD (Computerized Fluid Dynamics) programs to understand and optimize the flow conditions in the turbine and the steam exhaust.
- Experience based on extensive measurements carried out on test turbines and full-scale machines has increased the understanding of loss mechanisms and has been used to calibrate numerical tools, such as CFD programs.
- Modern design and manufacturing tools, such as CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing), combined with the latest milling machine technology, ensure economical and precise manufacturing of three-dimensional blades.

In addition, the study showed that it was economical to increase the reactor load to 115 percent. However, future operation at this load would require modifications to some of the components in the steam cycle.

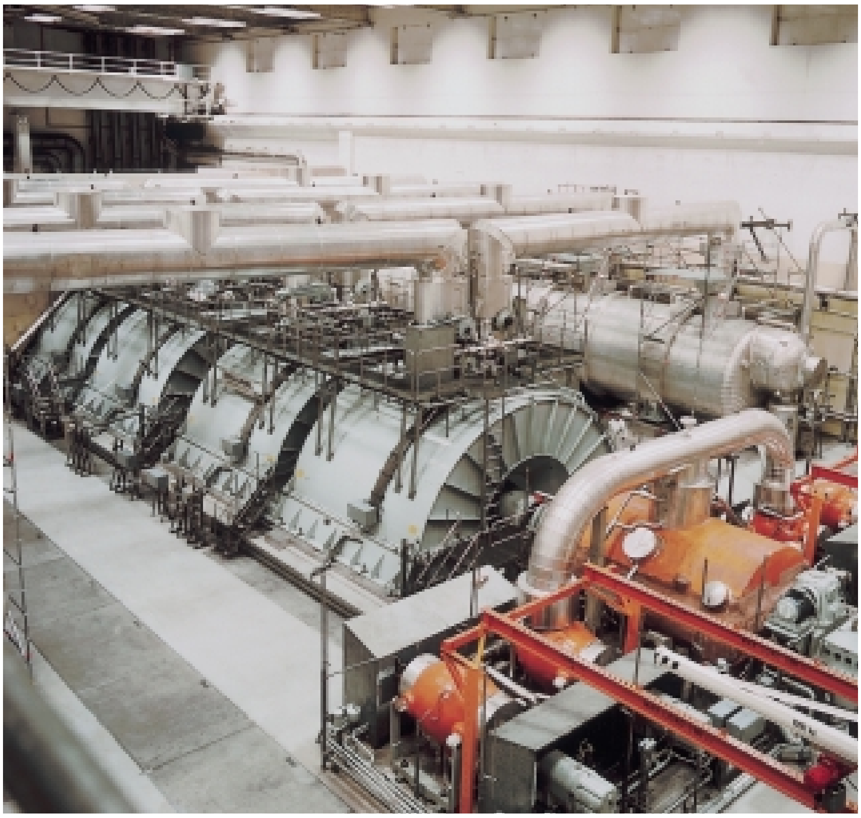
As a result of the promising results of the preliminary study, the customer gave the go-ahead for the investigation to continue in order to obtain quantitative information on the efficiency improvement, the scope of supply, and the delivery and installation times.

Four major conditions had to be fulfilled by the turbine supplier:

- Since the existing steam turbines did not suffer from any mechanical problems and could still be used even at increased reactor load, the increase in output due to the efficiency gain had to be large enough to justify the project economically.
- The proposed retrofit solution had to be based on proven technology to assure the customer that it would not have a negative impact on plant reliability.

Olkiluoto nuclear power plant (2 × 735 MW) in Finland **1**

Five-casing steam turbine in Olkiluoto 1.
In the foreground is the high-pressure turbine, behind it the four low-pressure turbines. **2**



- The installation of the new components would have to be completed during the very short planned outages, without any delays.
- Very high resistance to erosion-corrosion was required.

The preliminary study had shown that no standard LP steam turbine from the ABB product line was ideal for this retrofit application. It was therefore decided to carry out a feasibility study to look into the development of an optimum retrofit solution for Olkiluoto.

The decision was additionally supported by the fact that this LP turbine type is also ABB's most frequently sold LP turbine, with more than 100 rotors in service worldwide.

The feasibility study showed that to optimize the cost-benefit ratio for the LP steam turbine retrofit, only those parts which contribute to the efficiency improvement should be replaced. For the Olkiluoto project, the rotor, blading and blade carriers were selected for replacement. The inner casing had to be modified to fit the new blade carriers with an enlarged exhaust area 3. As a result, the guides for the blade carriers had to be manufactured with a larger diameter, which led to the location of some of the carrier supports having to be changed. To speed up installation and save time during the short scheduled overhaul period, it was decided to manufacture new, modified inner casings for the Olkiluoto LP turbines.

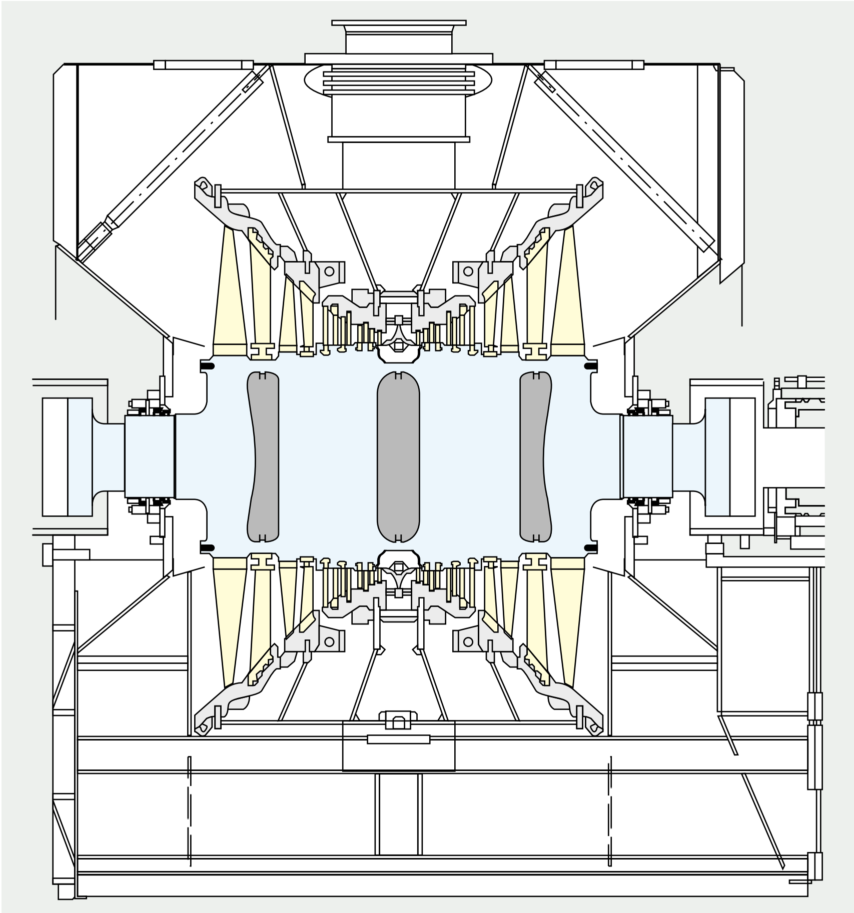
Based on the results of the study, the following LP turbine areas were identified as having the greatest potential for efficiency improvement:

- 3D high-performance reaction blading for the first four stages substantially improves the reaction stage efficiency compared with the former prismatic blading.
- An integral shroud on the next-to-last rotor blade results in lower tip leakage losses than with the former freestanding design with tip seal.
- A leaned last stator vane improves the working conditions for the last-stage blade and reduces losses due to vortices (secondary flow) at the end-walls 4.
- Improved transonic profiles for the blades in the last two stages reduce losses caused by shock-induced flow separation.
- An enlarged exhaust area reduces the exhaust losses.
- An improved diffuser geometry increases the pressure recovery in the steam exhaust section 5.

Together, these improvements result in a substantial gain in efficiency.

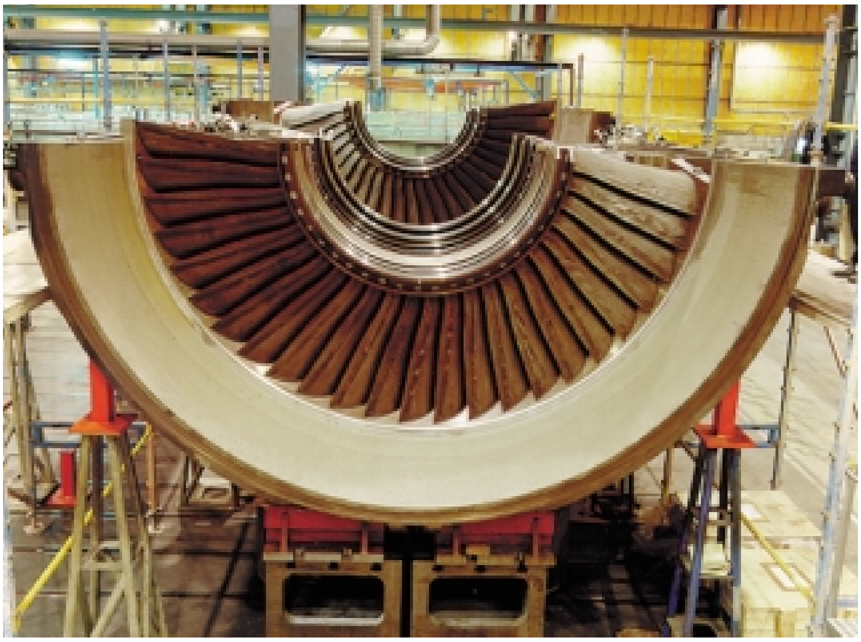
To reduce delivery time and development effort, it was decided to use existing technology for the rotating blades of the last two stages. The stationary blades for the last two stages were specially developed.

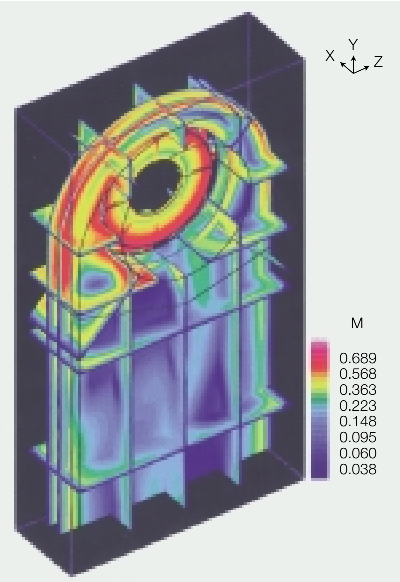
Since the customer required a solution with very high resistance to erosion-corrosion damage, four areas were defined for improved protection:



Cross-section of the LP steam turbine retrofit solution for Olkiluoto. The new rotor and the new blading are coloured blue and yellow, the new blade carriers in the inner casing grey. 3

Leaned last-stage stator vanes assembled in the inner casing 4





Example of the calculated flow from the last-stage blade to the condenser neck in the LP steam turbine exhaust section **5**

M *Mach number (local steam velocity)*

- Steam chamber (inlet and bleed chambers)
- Steam channels
- Axial seals between the steam chambers
- Horizontal joint planes

To protect the steam chambers, the inside of the inner casings and the outside of the blade carriers were arc spray coated with 13 % chromium steel.

The steam channels were coated with a nickel-chromium alloy containing 80% chromium carbide using a high-velocity oxygen flame spray gun. Spraying was carried out by a robot to achieve homogeneous thickness and quality **6**. All spraying was performed in the ABB Stal workshop in Finspång.

The axial seals between the steam chambers were changed to radial-axial seals by inserting a piston ring of 13% chromium steel. All sealing surfaces in contact with the ring are also made of erosion-resistant material. The sealing strips of the horizontal joint consist of overlay welds with 18/8 stainless steel. The casings were also equipped with a new adjustable bottom guide to simplify alignment.

The engineering department of ABB Stal in Sweden and the steam turbine development department of ABB Power Generation in Switzerland cooperated closely in preparing the feasibility study, which subsequently formed the basis for the final tender. All customer requests could be met with the proposed solution. The contract was awarded to ABB just a few months after the feasibility study had been completed.

Project execution

Based on the results of the 'load increase' feasibility study, the steam turbine of Olkiluoto 1 was adapted for operation at 107 % load during the 1996 overhaul. Olkiluoto 2 was adapted for 107 % load during 1997. Both units will be adapted for operation at 115 percent load during the overhaul in 1998.

Project milestones	Date
1. Initial discussions with customer. Modification of heat balances as basis for further studies	Apr 1993
2. Completion of preliminary study of possible efficiency improvements and reactor power increase	Sept 1993
3. Completion of feasibility study of LP retrofit solution	Feb 1994
4. Inquiry date	2 Mar 1994
5. Tender date	16 Apr 1994
6. Letter of intent from customer. Start of detailed development and design work	10 Jun 1994
7. Signing of contract	15 Aug 1994
8. Delivery of LP3 and LP4 for Olkiluoto 1	15 Apr 1996
9. Delivery of LP3 and LP4 for Olkiluoto 2	1 Apr 1997
10. Delivery of LP1 and LP2 for Olkiluoto 1	15 Apr 1997
11. Delivery of LP1 and LP2 for Olkiluoto 2	1 Apr 1998

Site work

Planning of the site work started on June 10, 1994, the date of receipt of the letter of intent. The work on the turbine had to be coordinated with all the other activities on the turbine floor, including the generator retrofit, turbine control and safety system retrofit, and customer activities.

During the outage in 1996 the complete generator, which weighs 400 tonnes, was exchanged and the turbine control and safety system retrofitted. The high-pressure (HP) turbine was opened for the purpose of changing the swallowing capacity. The generator was replaced in 18 days, as stipulated by the contract. Retrofitting of the turbine control and safety system, adaptation of the HP steam turbine and retrofitting of the LP turbines 3 and 4 required only 16 days.

The LP turbine retrofits (turbines 1 and 2) were carried out during the scheduled outage in 1997 and took 14 days (in fact, 13 days and 19 hours) **7**, in accordance with the contract.

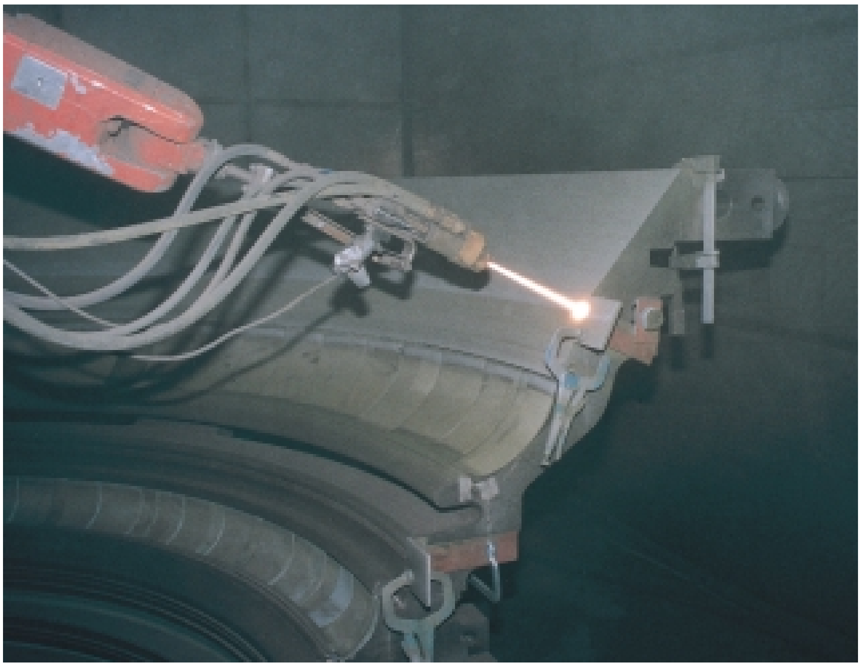
To ensure that all these activities could be carried out in such a short time, all the activities were planned in detail. A special crane time schedule was drawn up, showing the date and time, hour by hour, of all lifting activities **8**. The customer, ABB and subcontractors collaborated closely in the planning.

Factors contributing to the success of the project

The speed with which the site work was successfully completed was due to a combination of know-how, experience in project management, and close cooperation with the customer. Contributing factors included well-trained, dedicated personnel, strong customer support and a permanent site supervisor, who coordinated the detailed planning on behalf of the client and ABB. A service planning, quality and administration tool called SIQS, for Service Integrated Quality System, assisted in this area.

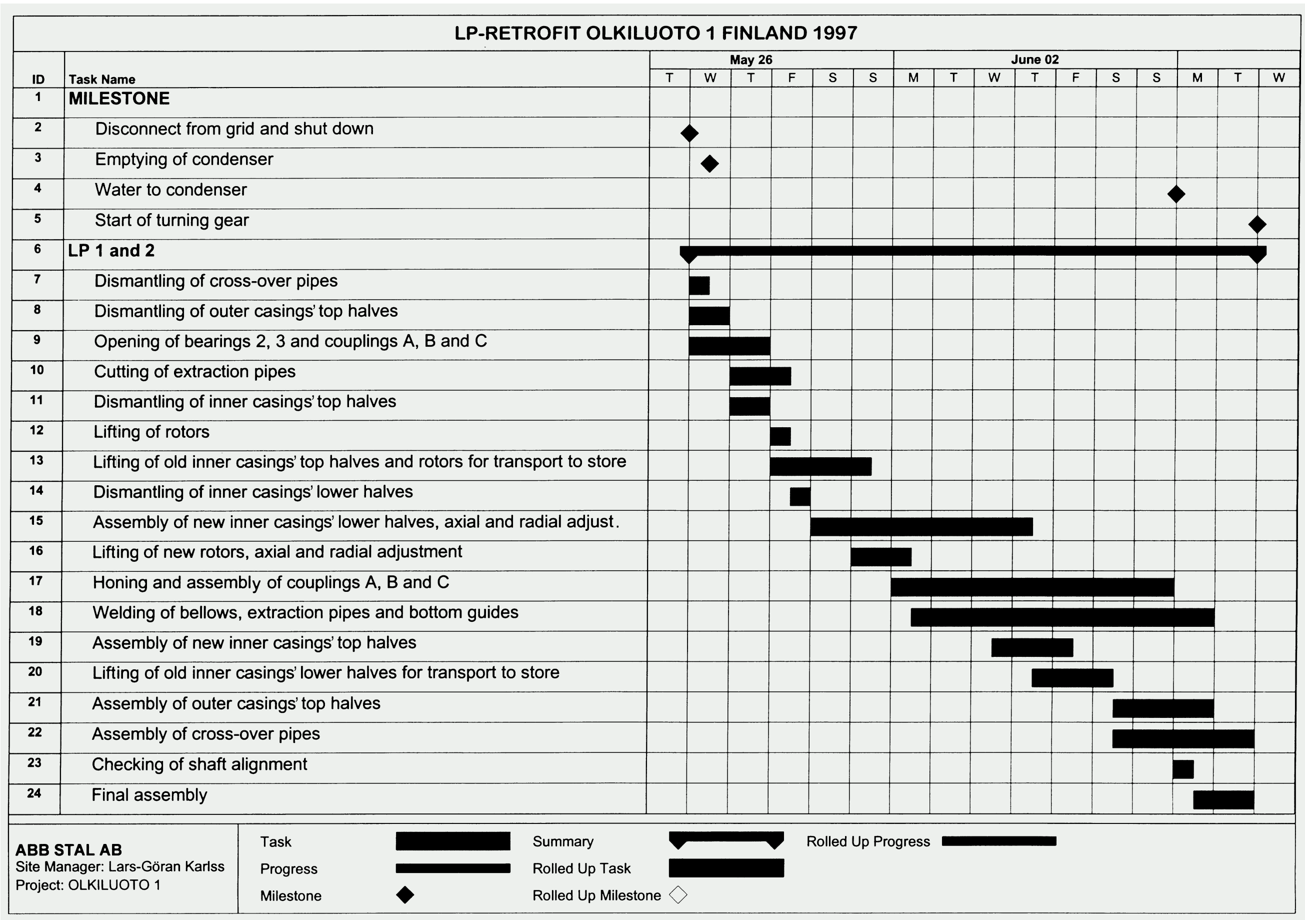
In all, there were 70 to 120 people from ABB Stal on the site. Engineers from the design department were in attendance during the entire outage period to make sure that there were no delays in contacting the home office. This meant that problems could be solved immediately, on the site. Work on the site went on 24 hours a day, 7 days a week.

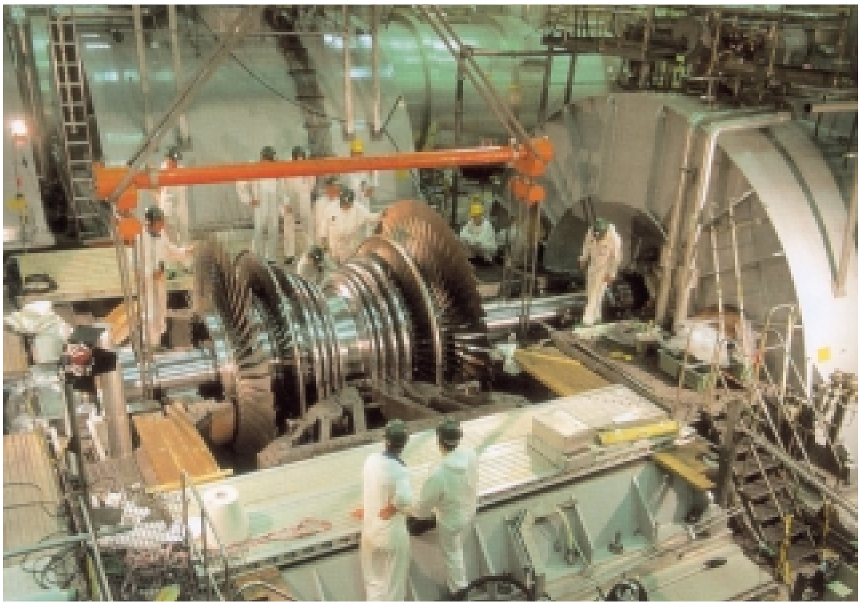
Also, meetings were held with subcontractors and the customer before the outage to discuss all activities, including the crane operations.



Robot being used for high-velocity oxygen flame spraying of the blade carrier **6**

Time schedule for the site work needed to install the new LP inner blocks during the Olkiluoto 1 overhaul in 1997 **7**





One of the new LP turbine rotors being lifted into position **8**

tional customer requirements, such as a short delivery time and very short on-site installation, have to be met. Steam turbines in many power plants do not suffer from mechanical problems, and for these units the increase in output possible by improving efficiency has to be sufficiently large to justify the project economically. Also, the continuing deregulation of the electricity market is making utilities look for a faster return on investment in retrofit projects.

All these aspects applied to the Olkiluoto project, which was successfully executed from project initiation to final performance measurements due to the close cooperation between the customer and supplier and between the different ABB companies involved.

Performance measurements

Measurements were carried out during three test series to determine the performance of the old and new LP turbines at Olkiluoto 1. Between April 12 and 23, 1996, a baseline performance test was carried out prior to any changes being made. An intermediate performance test was then carried out between November 4 and 12, 1996, after LP turbines 3 and 4 had been replaced. Finally, a verification performance test was carried out between November 14 and December 5, 1997, after the replacement of the LP turbines 1 and 2.

The planning and execution of the tests focused on obtaining a low relative uncertainty between the three test series. To detect possible changes in the steam cycle and to evaluate the changed swallowing capacity of the HP turbine, a tracer measurement was made during the baseline and verification test series. This measurement also shows the absolute performance of the key components involved.

Some significant changes were made between the baseline test and the intermediate test:

- The swallowing capacity of the HP turbine was changed for the thermal load of 107 percent.
- The generator was replaced during the overhaul in 1996.
- The outer tubes in the condenser were replaced.
- Two drain coolers were replaced.

The tracer measurement was carried out by ABB Turbo Systems and the thermal measurement by ABB Stal. All the measurements were performed in close cooperation with the customer.

The results show an increase in output of 36 MW (ie, almost 5 %) at 100 % load due to the retrofitted LP turbines. The rise in output can be fully attributed to the improved efficiency of the modern LP steam turbine technology used, and exceeded the guarantee value.

Concluding remarks

To be successful in the steam turbine retrofit business, it is essential to develop solutions in close cooperation with the customer rather than just present a product 'off the shelf'. To be competitive today, it is not enough to just offer a package that increases efficiency and availability; additional customer requirements, such as a short delivery time and very short on-site installation, have to be met.

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