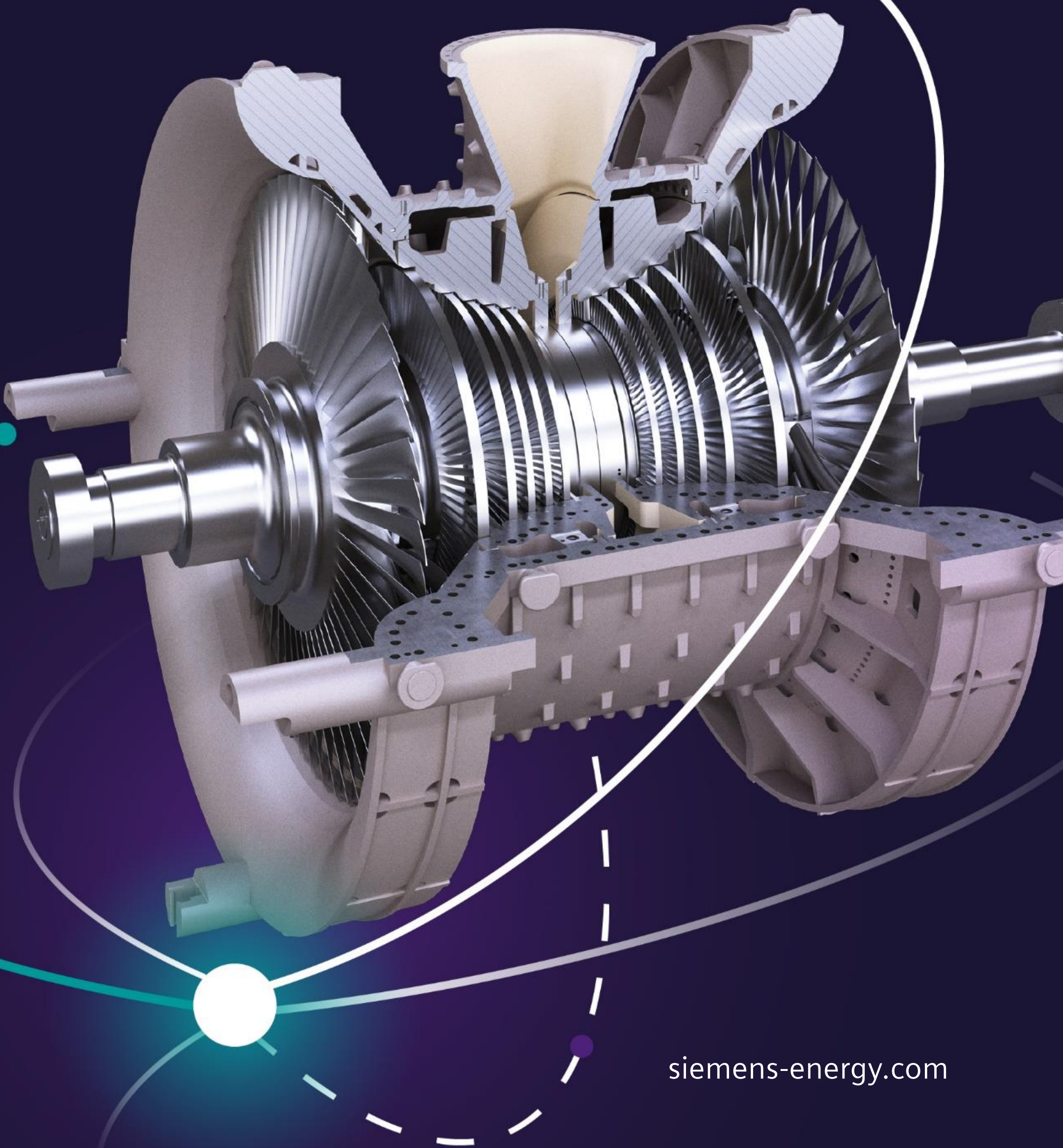
Modernizing of Steam Turbines and Condensers at Ibbenbüren Coal-Fired Power Plant



Reprint from
VGB PowerTech 8 | 2012

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Abstract

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The Ibbenbüren hard coal-fired power plant, owned by RWE Power AG had an initial installed rated gross power output of 752 MW and was commissioned in 1985. In 2009 Siemens modernised of the high pressure turbine, the intermediate pressure turbine, the two low pressure turbines and the two condensers with deployment of the latest turbine and condenser technology. Prior to the project, a detailed plant assessment in cooperation with the power station's owner RWE was conducted. A project-specific product development resulted from the assessment study deliverables, whereby only reasonable economical and environmental approaches have been chosen to achieve the business and emission goals of the customer.

The stated customer objectives were: performance increase (efficiency increases of all turbines and the condenser) associated with CO_2 reduction, lifetime extension, improved reliability and improved availability. These objectives could be achieved by installing new turbine rotors and inner casings with advanced blading and seal technologies combined with the installation of optimised condenser tube bundle modules.

Once the retrofit was completed and the unit returned to operation, a performance increase of 86 MW was observed. About 43 MW resulted from increased thermal efficiency so-called „green MW" that means additional power increase with the same fuel consumption, leading to an avoidance of up to 260,000 t CO_2 per year. Furthermore, the turbo-set showed better operating characteristics than prior to the modernization and a flexibility improvement.

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Introduction

Ibbenbüren Power Station operated by RWE lies in the northwest of Germany, in the federal state of North Rhine-Westphalia. Construction work on the current single-unit 752-MW power plant began in July 1981, and electric power was first supplied to the grid in July of 1985. Ibbenbüren Power Station fires some 1.5 million tons of anthracite per year. The coal is transported directly from the neighboring mine to the power plant by conveyor belt. The anthracite is extremely hard and has a very low content of volatile components.

The power plant has a gross operating range from 220 MW_{gross} to 752 MW_{gross}, with a maximum short-term output of 782 MW_{gross} and an auxiliary power requirement of approximately 43 MW. In the spring and summer months, the plant is operated at full load during the day from Monday to Friday and predominantly at part load evenings and on weekends. Part load refers to an output between 220 and 460 MW. In fall and winter, the plant operates primarily at full load. Prior to the modernization project, the plant had generating an output of more than 83 TWh_{net}, and had clocked up 696 starts and 142,800 operating hours.

Ibbenbüren is a conventional thermal power plant, with a single membrane wall Benson-type boiler. The boiler has 32 combined coal and oil downshot burners and two slag tap furnaces. Each furnace is designed for firing temperatures ranging from 1,600 to 1,800 °C. Only one of the furnaces is in operation at minimum stable generation. Molten slag from the furnaces pours into water baths to solidify as granulate at a rate of 25 tons per hour. The boiler has eight vertical spindle mills that are each capable of pulverizing 37 tons of coal per hour. There are two axial-flow FD fans and two axial-flow ID fans.

The Siemens steam turbine consists of a single-flow HP turbine section in barrel construction, a dual-flow IP turbine section, and two dual-flow LP turbine sections. The HP turbine operates at 187 bar and 527 °C, the IP turbine at 31.6 bar and 527 °C, and the LP turbines at 6.1 bar and 297 °C. The turbine operates in bypass mode during startup. The Siemens generator has an apparent power of 850 MVA and is cooled with hydrogen only.

The power plant was in very good condition as a result of regular maintenance. Major maintenance measures had been performed at regular intervals, especially in the flue gas purification system, and an extensive project had been started to replace the plant instrumentation and control systems. However, no significant modernization measures had previously been implemented to increase plant efficiency and output. The plant had reached half its service life, and maintenance expenditures would have had to be increased in a number of areas to maintain plant availability. It was also necessary to replace several components which would have reached the end of their service life before the plant would reach the end of its economic lifetime.

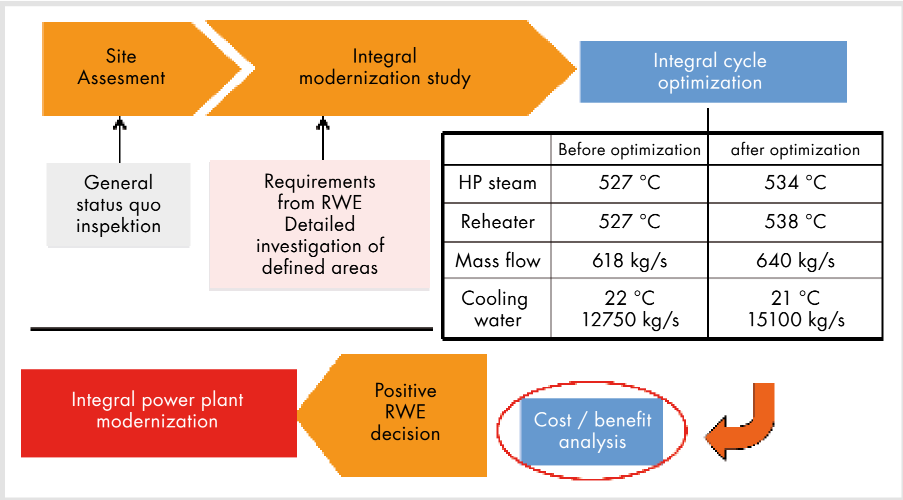
Increasing competition in the energy market and the anticipated construction of new power plants in the following years gave rise to the question of how the power plant management team should react to changing market conditions so as to ensure that the power plant will also continue to remain profitable for RWE Power in the future. It was further asked what measures would enable the following goals to be achieved:

- Increased efficiency with associated reduction in specific CO2 emissions
- Increased output
- Increased flexibility
- Lifetime extension by an additional 150,000 operating hours
- Improved long-term availability
- Reduced or unchanged short-term and medium-term maintenance expenditures.

The power plant management began a systematic review of the entire process of electric power production at the power station. The objective was to analyze the entire power plant without immediately focusing on high-cost solutions. In all cases, any possible upgrades should be conducted within the time frame of a standard overhaul. However, it quickly became apparent that the support of external specialists was needed to ensure effective assessment.

Analysis of Overall Plant

In 2006, Siemens was commissioned to work with the power plant's engineers to



	Before optimization	after optimization
HP steam	527 °C	534 °C
Reheater	527 °C	538 °C
Mass flow	618 kg/s	640 kg/s
Cooling water	22 °C 12750 kg/s	21 °C 15100 kg/s

Fig. 1. Overall plant analysis.

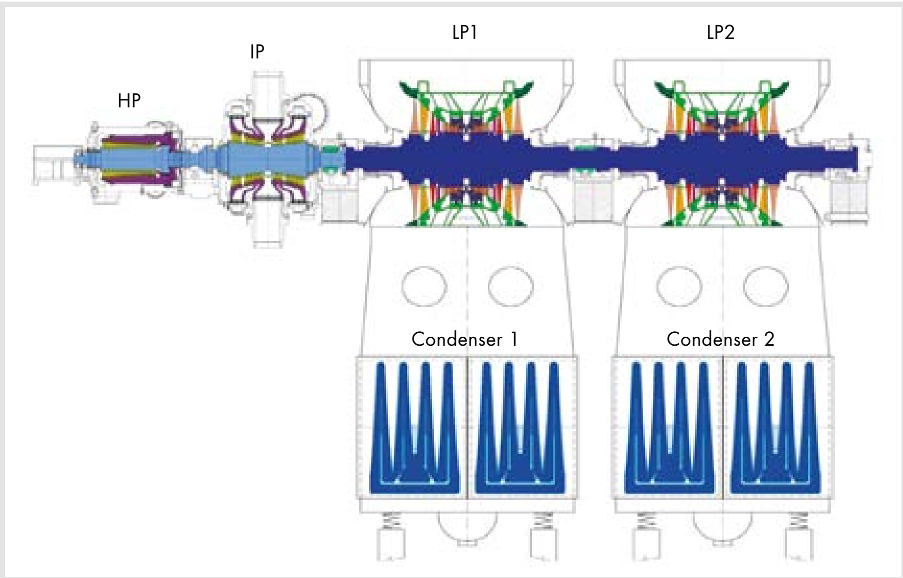


Fig. 2. Modernization scope of supply (shown in color).

identify areas for potential upgrades. A joint team was formed between plant and Siemens staff with the task of assessing the entire power plant. The analysis included examination of original drawings and energy-flow diagrams together with operational data. The goal was to identify the current operating points and the maximum theoretical operating points based on the following plant components:

- All thick-walled parts
- Main pumps and fans
- Safety valves
- Main and secondary cooling water systems, including cooling towers
- Generator and associated power breaker and transformer.

The ideas from the power plant management were systematically reviewed for feasibility and evaluated. The results were regularly communicated back to the power plant to enable the performance of a detailed cost/benefit analysis. Investigation of the main components revealed that steam temperature and mass flow rate could be increased in the HP superheater and reheater sections of the boiler, and furthermore that it would be possible to increase the cooling performance of the main cooling water system. Various approaches were considered as to how this information could best be implemented in upgrade measures. The limits of the electrical system were also identified. In order to achieve a future performance enhancement, the generator cooling system had to be improved, which was achieved by increasing the hydrogen gas pressure and installing larger internal coolers.

Consideration of the entire steam, condensate and feedwater cycle also enabled determination of the boundary conditions and specification of modernization measures for the auxiliary systems. Only by appropriate measures in the auxiliary systems could the best possible outcome be achieved for the modernization of the steam turbine and condenser.

The final cost/benefit analysis performed by power plant management yielded a positive economic result. The tendering procedure for the modifications was started in early 2007, and Siemens was awarded the contract for modernization of all the steam turbines and condensers in October of 2007. An overview of the overall assessment process is shown in Figure 1.

Modernization measures

The overall plant analysis identified the modernization potential for all of the existing steam turbines and condensers. The scope of modernization included renewal of all internal parts of the turbines, as shown in Figure 2. Specifically, these are new inner casings and rotors, combined with new blading and seal technology. The new blade paths were designed based on state-of-the-art aerodynamic considerations, resulting in optimized blade efficiency for each individual turbine.

Forged monoblock rotors with forged couplings were used. 100% ultrasonic volume testing was performed on the unfinished forgings. With the shaft designed in accordance with Siemens' quality criteria, nondestructive testing need not be repeated again until after an additional 200,000 operating hours.

It was deemed best to replace the four tube bundle modules in both condensers at Ibbenbüren Power Station with cutting-edge technology. This allowed the low-pressure turbines to be designed with larger final blading stages, resulting in higher power output.

High-pressure (HP) turbine

The HP turbine in Ibbenbüren is of single-flow design with an axially split inner casing and a barrel-type outer casing. The outer casing, consisting of a cast barrel with no axial joint and with a flanged cover, was reused in the modernization. The barrel-type HP turbine was shipped to Siemens' Manufacturing Plant in Mülheim for disassembly and modernization during the modification work. This entailed an overhaul of the outer casing and installation of modernized components, with all work following Siemens' strict quality procedures.

The internal parts replaced in the HP modernization (Figure 3) for increasing efficiency mainly consisted of new inner casings and rotors, each with new reaction blades, with the first blade stage implemented as a diagonal low-reaction stage. New and innovative seal technology was also implemented, such as abradable coatings in the area of the balancing piston and brush seals in the shaft seal area to supplement the standard labyrinth seals.

Advanced blading technology

A significant efficiency increase was achieved by replacing the stationary and moving blading. The blade path was designed by numerical optimization with variation of stage reaction and stage loading. Implementation of three-dimensional twisted tapered blade profiles together with optimized seal geometries yielded a significant reduction of profile, secondary and tip clearance losses.

Special attention was given to production accuracy, surface quality, and damping behavior. Frequency adjustment of rotating blades with integral shrouds is not required, as the mutually supported shrouds generate such a strong damping effect as to eliminate any significant vibration amplitudes. Tip clearance losses were significantly reduced by implementing staged castellated labyrinth seals above the blading.

The first stage was implemented as a diagonal low-reaction stage in which energy conversion takes place mostly in the diagonal stationary blade ring. This reduces the thermal load on the rotor by reducing the temperature. The configuration of the stationary blading simultaneously ensures that the high-temperature HP steam does not flow directly onto the rotor.

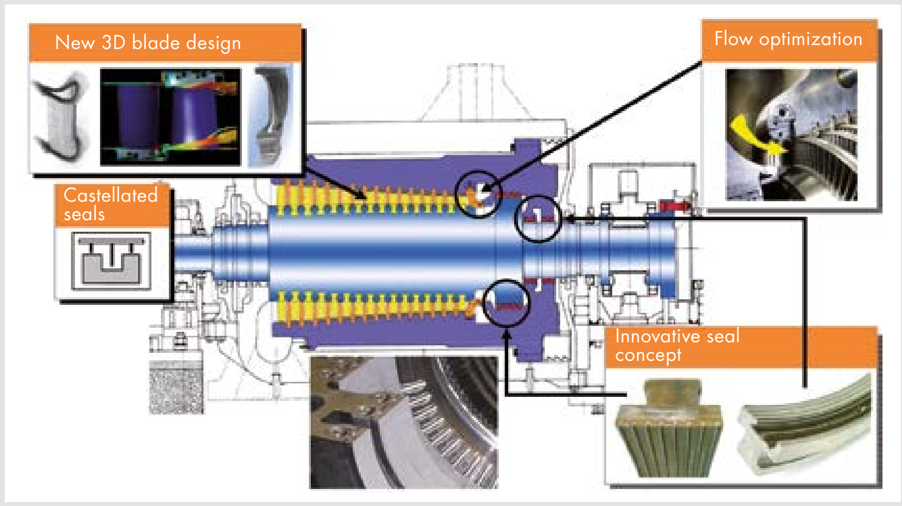


Fig. 3. HP modernization measures.

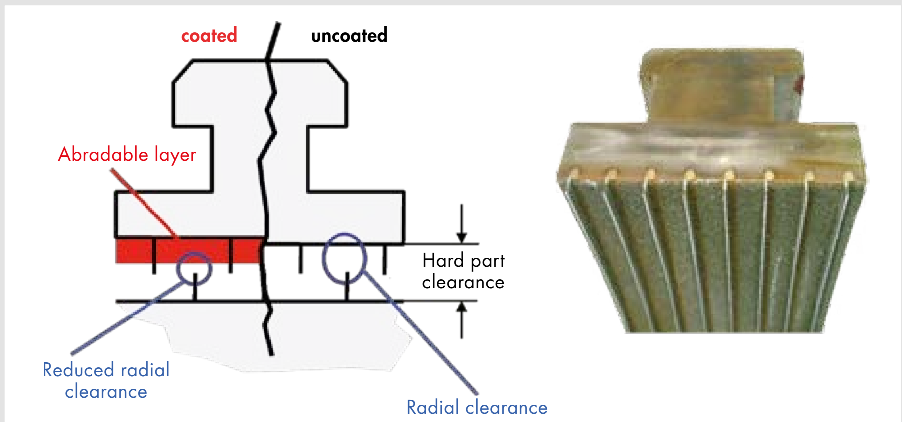


Fig. 4. Abradable seal.

Advanced seal concepts

For the HP turbine modernization, innovative seal technologies were employed in the area of the rotor and balancing piston to supplement the standard labyrinth seals. In principle, the concept of labyrinth seals on spring-backed seal segments was reused, with no changes in casing or rotor geometry in the area of the seals and segments. Labyrinth seals are a very versatile type of seal, as they are designed for use under extreme service conditions.

Thin abradable coatings were developed to reduce leak-off steam flow. These coatings were applied on spring-backed segments between the seal tips in the area of the balancing piston seals (Figure 4). This measure enabled a reduction in the mass flow of leak-off steam through the gap by up to 30 % compared with uncoated seals due to the reduced radial clearance. The abradable coatings consist of a nickel-chromium alloy and bentonite, the porosity of which permits local penetration of the seal tips into the coating, preventing damage to the seal tips. If rubbing occurs, the function and geometry of the seal tips is only insignificantly impaired. Grooves are scored in the abrasive coating, but this has only a slight effect on seal performance. A further advantage is the increased clearance between the hard metal parts of the seal segment and rotor, thus increasing operating reliability. This technology is especially suitable for higher pressure drops such as in balance pistons.

The standard labyrinth seals in the area of the shaft seals were supplemented with brush seals as a further modernization measure. The brush seal consists of a backing ring and a guard ring as well as a package of bristles and is installed in place of a standard seal strip. The installation of brush seals reduces the clearance between the seal and rotor.

Leakage losses can be reduced by up to 50 % in comparison with normal seals. This can be attributed to the so-called „blowdown effect“, whereby the brushes are drawn towards the rotor in operation due to the resulting underpressure, thus further reducing the clearance.

Intermediate-pressure (IP) turbine

Modernization of the IP turbine included the following measures:

- New monoblock rotor and new rotor seal segments
- New inner casing
- New three-dimensional blading with variable reaction and shrouds
- Inlet flow optimization with diagonal low-reaction inlet stage.

Low-pressure (LP) turbine

In modernization of the LP turbine, special attention was given to increasing the cross-sectional area of the exhaust outlet from 10 m^2 to 12.5 m^2. In conjunction with the simultaneous modernization of the condensers, this yielded an additional increase in output. In connection with flow optimization measures , this resulted in significantly reduced exhaust losses. The scope of the modernization is presented in Figure 5. In addition to customer-specific three-dimensional blades in the drum stages, this also included standard Siemens blading in the last four blade rows. The last row of moving blades was implemented with free-standing blades, while all other blade rows used an integral shroud (Figure 6). The leading edges of the final stage were laser hardened to protect the last row of blading in particular from droplet impact erosion. The hollow stationary blades in the last-stage were implemented with drainage slits to prevent the formation of a water film on the blade surface.

Condenser module replacement and "cold end" optimization

The overall efficiency of a fossil-fired power plant is strongly affected by the performance of its condensers. Poor condenser performance results in thermodynamic losses and thus reduces the profitability of the power plant. Replacing the complete condenser modules (Figure 7) offered the opportunity to implement the newest

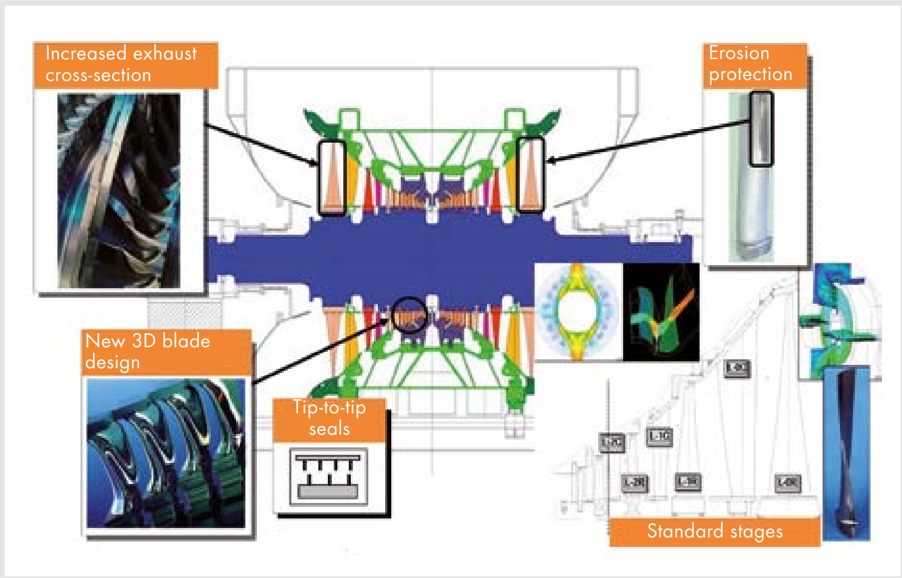


Fig. 5. LP modernization measures.

design features and materials to increase condenser efficiency. Generally, the unique Siemens condenser tube-bundle design ensured optimum steam distribution across the tube bundles, thus reducing the pressure drop in the condenser and therefore lowering the backpressure at the LP turbine exhaust.

The modular replacement also provided the opportunity to increase the number of tubes and to implement these with a smaller outside diameter, thereby increasing the effective cooling surface area. Tubes of stainless steel were used instead of brass, enabling smaller wall thicknesses and smoother surfaces. This resulted in a reduced cooling-water pressure drop across the condenser and thus an automatic increase in cooling water flow from the pumps. A further increase in cooling water flow was achieved with the simultaneous modernization of the cooling water pumps.

All of these measures enabled the implementation of larger LP exhaust cross-sectional areas, resulting in increased power output due to the lower LP exhaust losses. The improved condenser performance together with the larger LP turbine enabled more cost-effective plant operation during hot summers and cold winters. The „cold end“ optimization also included replacement of the cooling tower internals.

Performance of modernization and overhaul measures

The major overhaul of the power plant, including the modernization measures, was scheduled to be performed over a period of 72 days and was completed with no delays. Siemens performed the following additional work in addition to modernization of the steam turbines and condensers:

- Overhaul of all hydraulic systems associated with the turbine protection system
- Overhaul of overspeed bolts and main oil pump
- Replacement of selected high-temperature fasteners
- Lifetime assessment of thick walled pressure vessel components and minor repair work as necessary
- Selected replacement or re-metalling of all turbine bearings
- Enhancement of protection system.

Siemens also overhauled the generator, including inspection of the generator rotor, installation of a replacement exciter, and the installation of upgraded coolers. Other activities were performed by power plant personnel or third-party contractors:

- Inspection of main valves
- Upgrade of turbine building crane to enable accommodation of the additional weight of the LP rotors
- Inspection and cleaning of the turbine oil systems.

Quality assurance

RWE was involved in all stages of Siemens quality assurance, from the plant assessment study through project development and processing at the Siemens' Mülheim Manufacturing Plant until final implementation at Ibbenbüren Power Station. Lessons learned from similar modernization projects with RWE were incorporated in the quality assurance program. During the manufacturing process, the quality assurance system was supplemented with defined customer witness points to meet the high quality standards of both parties.

Occupational health and safety

Special attention was given to occupational health and safety during performance of the work. Two dedicated safety officers were deployed by Siemens to monitor and control safety aspects throughout the entire modernization and overhaul of the turbine shaft train. Daily onsite meetings were held between RWE and Siemens where health and safety, tagouts and lockouts, quality and environmental issues as well as technical issues were discussed and resolved.

Commissioning

Siemens performed cold commissioning of the turbine and generator with the support of plant personnel, and the unit started turning gear operation on October 20, 2009. The first milestone was thus achieved on schedule. A hot commissioning period of up to seven days was planned to accommodate testing of the HV systems, boiler protection systems and balancing of the turbine shaft train.

Recommissioning of the turbine shaft train was uneventful, with Siemens personnel monitoring runup. Turbine vibration behavior was monitored using a Siemens vibration monitoring system which was connected to the STUDIS equipment in the power plant. Precision balancing of the turbine generator set was performed during hot commissioning of the power plant.

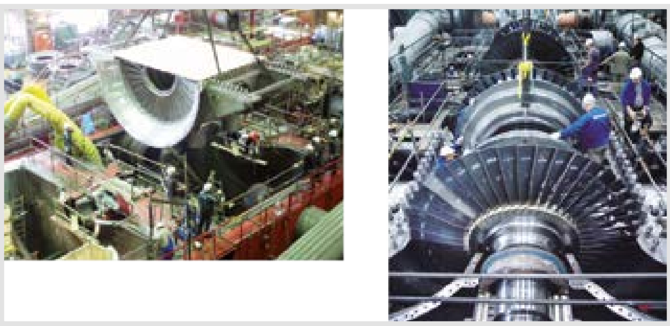


Fig. 6. Installation of modernized LP turbines.

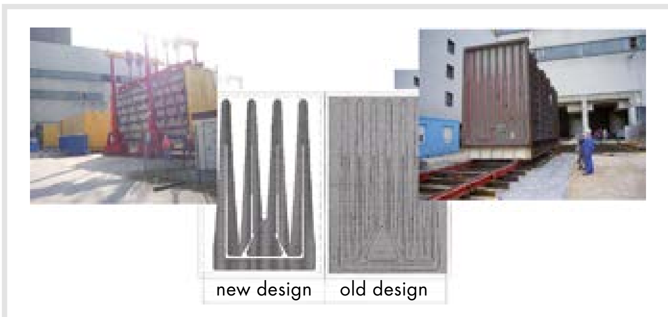


Fig. 7. Condenser module exchange.

Trial operation, scheduled for a period of eight weeks, was uneventful. During this period, the plant demonstrated improved flexibility and operating performance. Following various optimization activities on the plant's new instrumentation and control system, a gross output of 838 MWe was achieved.

Acceptance testing. The turbine heat rate was measured in May of 2010, shortly before six months of operation were completed. The tests were performed at various loads. The positioning and type of instrumentation was jointly agreed between Siemens and the RWE testing team. In addition to measurement of the turbine heat rate, the RWE testing team performed a thermal efficiency measurement of the overall power plant. The measured heat rate complied with the contractual obligations, and the efficiency of the plant met the requirements as laid out in the original business case. The throughput capacity of the machine was calculated from measurements taken during heat rate testing, and it was confirmed that this also met the contractual obligations.

Inspection/Overhaul. Maintenance requirements for the plant have been greatly reduced in comparison with those before the modernization. No major inspections of the turbine sections are planned for the next few years. This has significantly reduced maintenance costs for the next few years, and allows plant operation for many more years without the need to replace any major components. The plant has been in operation for over three years with no major issues and has demonstrated a high degree of reliability.

Conclusion

Results

The successful modernization measures (Figure 8) yielded the following results:

- Increase in generating capacity: 86 MW
- Improved energy efficiency: 43 MW resulting from increased thermal efficiency, so-called "green MW". This means additional power output with the same fuel consumption.
- Reduced emissions: A considerable CO_2 emission reduction of about 260,000 tons/year was achieved. This helped to ensure achievement of German CO_2 targets.
- Improved availability and reliability
- Lower production and maintenance costs
- Improved profitability
- Improved operating characteristics (rotor and bearing vibrations and acoustic emissions)
- Increased operational flexibility
- Lifetime extension until 2030.

Critical success factors

The major success of this modernization project can be attributed to various reasons. The most important success factors are listed below:

- Establishment of a project organization characterized by open communication and a willingness to jointly resolve issues;
- Joint elaboration of a detailed project plan with clear interfaces and responsibilities;

Fig. 8. Successfully modernized turbine generator set.

- Establishment of a culture of occupational safety, health and environmental protection which was implemented throughout the entire project;
- Support of power plant personnel by Siemens Engineering in modernization of the cooling tower, the cooling water pumps, the generator cooling system and the boiler to ensure optimum coordination of the modernization measures;
- Detailed quality assurance plans (manufacturing, assembly and field erection) accounting for the results of earlier projects;
- Detailed planning of commissioning, commitment and hard work by power plant personnel and the Siemens commissioning team during commissioning and trial operation.

Published by

Siemens Energy Global GmbH & Co. KG
Freyeslebenstr. 1
91058 Erlangen, Germany

For the US Published by
Siemens Energy Inc.
4400 Alafaya Trail

Orlando, FL 32826-2399, U.S.

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Article No PSPG-B10176-01-7600