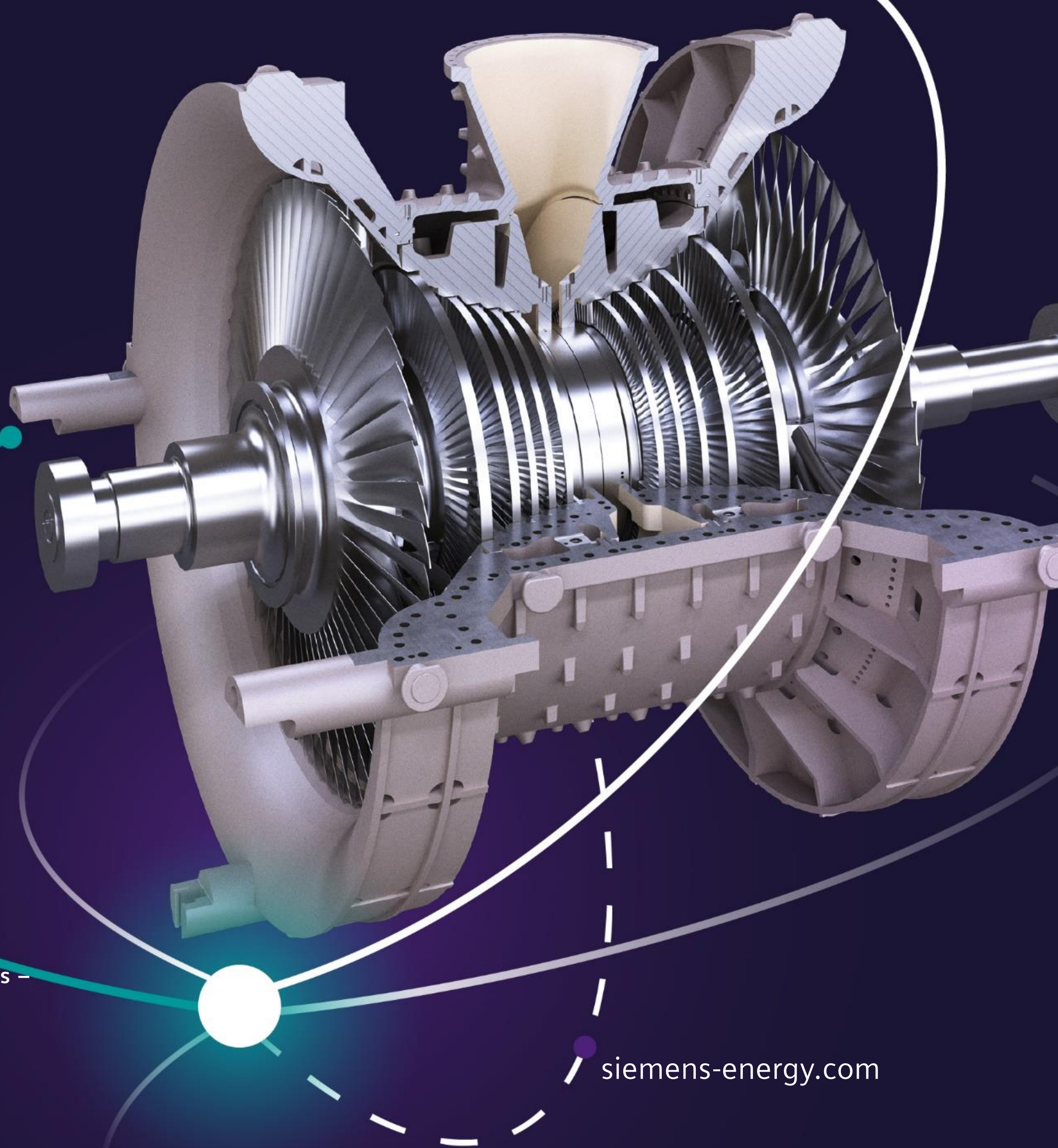
Modernization approach for subcritical LMZ K200/K300 & KWU 200/500 MW steam turbine units with thermal upgrade up to 600°C based on the recent steam turbine modernization experience in China



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1 Abstract

Reducing the greenhouse effect (GHG) has become one of the most important factors for energy policies worldwide. There are also clear trends towards the conservation of fossil fuel resources and requirements to reduce CO_2 emissions as well as other pollutants. In India, the rapid economic growth is leading to strong demand for power and new power projects are becoming more difficult as the availability of the resources like fuel, land, and water in India are decreasing.
Due to the rapid advancement in "Steam Turbine Technology" in the last decade, thermal upgrades with the advanced steam parameters up to 600°C for old Indian Original Equipment Manufacturer (OEM)/ Non-OEM plants with flexible operation is a feasible option today and will help to improve the efficiency, flexibility, availability and reliability of the modernized power plants with reduced carbon foot print.
In addition, future electricity markets with high levels of renewable power generation are expected to be typically forcing radical changes on the fossil fuel steam power plants operating profile in these markets.
As a result, many existing Steam Power Plants (SPP) designed for base-load operation may have to change to flexible mode, requiring optimized startup performance. As many of the plants have already completed the designed lifetime (and many in the verge of completion) in India, it is not practically a feasible option to run these plants in flexible mode. The option left is, shift to flexible mode only after the old turbines are modernized using state-of-the-art materials and technology-enhanced components such as blades, sealings, casings & rotors.
In short and near medium term, Energy Efficient Renovation & Modernization (EE R&M) along with Lifetime Extension(LE) measures to extend the normal design life of existing aging power plants is an economical option for addressing the continuously growing power demand for India and for transformation of the existing conventional electricity generation with new, more efficient, low carbon emitting technology, considering the fact that coal shall remain a dominant fuel for power generation in next decades.
This paper focuses and emphasizes on some of the opportunities which shall bring profound changes for the future outlook of present "Mods & Upgrades" R&D programs and design principles. The focus is on the SIEMENS Energy design solution for the modernization of old subcritical LMZ K200 (Indian200-MW)/K300 (Chinese 300-MW) & KWU 200/500 MW Indian power plants, considering the possibility of future thermal upgrade up to 600°C with flexible operation and challenges moving forward.

2 Introduction

The installed energy capacity in India is around 366 GW, and even so, the addition of up to 99 GW capacity is planned to address the shortage of power and peak requirements [1],[2]. The actual execution of new power plant projects, however, are becoming more and more difficult as the availability of fuel, land, and water in India are decreasing.
At the same time, numerous installed power plants are reaching the end of their design life and are running with the risk of electrical power outages if a lifetime extension program is not pursued. The Indian government has addressed this issue in its eleventh and twelfth "Plan for Renovation, Modernization and Life Extension of Thermal Power Plants" [1]. Coal-fired steam turbine power plants account for a major share of power generation capacities in India and because of their age, they are prime candidates for upgradation via the R&M/LE program to improve their output, reliability, availability and environmental compatibility.
The following three main frames are concerned in this paper:

- 200/210/300-MW LMZ units
- 200/210-MW KWU units
- 500-MW KWU units

Energy Efficient R&M (EE R&M) along with Lifetime Extension to prolong the normal design life of existing aging power plants is an economically attractive option for addressing the continuously growing power demand.
The key goals are as follows:

- Extension of the steam turbines' life beyond the design life.
- Increase plant efficiency with heat rate improvement and power output with no thermal cycle change.
- Decreased maintenance costs of the steam turbines.
- Improve design weaknesses of the steam turbines.
- Flexibility in turbine operation, if desired.

3 Approach of lifetime extension with thermal upgrade up to 600°C

Like every technical product, the steam turbine is designed for a certain lifetime. Since the attainable lifetime as well as the reliability and availability of a steam turbine depends heavily on its operating regime and the history of the unit, specific knowledge about the unit is needed to ensure an optimized lifetime management of the components. Key contributors to assessing the remaining lifetime of critical components of a steam turbine are non-destructive tests as well as sample tests, which are being performed during outages [1].
Nevertheless, the lifetime of a steam turbine can be extended by specific repair procedures as well as the exchange of specific components. Replacing old key components with state-of-the-art materials and technology enhanced components such as blades, sealings, inner casings

and rotors provides increased efficiency, availability, optimized maintainability and operational flexibility benefits due to the technology advancement employed.
In addition, advanced steam parameters with thermal upgrade up to 600°C for old Indian OEM/Non-OEM plants modernization with flexible operation shall also help to improve the efficiency, flexibility and availability of the modernized power plants with reduced carbon footprint. As an example, for 500 MW plant with a load factor 70% this translate into a decrease of CO_2 emission with approx.1,50,000 tons per year approx. and with a life time extension by an addition of 1,50,000 operating hours while reducing coal consumption of approx.10 - 15% [2]. Increase of steam temperature from 540°C to 600°C [(Main Steam (MS) & Hot Reheat Steam (HRH)] significantly improves heat rate and plant's efficiency in order to reduce CO_2 emissions which itself make an attractive contribution to save the environment [1].
However, this may need boiler upgrade for high temperature subcritical steam condition and adoption of Balance of Plant (BOP) as and where necessary.

4 Steam Turbine modernization in China with thermal upgrade

Steam turbine (ST) modernization globally with high temperature sub-critical technology has successfully commissioned and implemented in China with required test runs at the end of 2019.This design innovation has demonstrated a new method to contribute to CO_2 reduction which is a priority in the China Market.
ST Modernization scope and contribution to greener future:

- Implementation of a high-temperature subcritical upgrade for a 320MW steam turbine
- In this project, the main steam (MS) and hot re- heat steam (HRS) temperatures were raised from 537°C to 600°C.
- With the implementation of innovative technologies, significant increased efficiency is planned to be achieved with a lower heat rate and without changing steam flow.
- This can result in fuel reduction which is approximately equivalent to ~ 1,70,000 tons CO_2 reduction per year considering the same power output.

This innovative design approach of Steam Turbine modernization that incorporated high temperature sub- critical technology for main and reheat steam temperatures up to 600°C, demonstrated a new method to contribute to CO_2 reduction which is a high priority in the China Market.
Steam temperature is the key factor in influencing the power generation efficiency and coal consumption of a steam turbine. In this project, the main steam and hot reheat steam temperatures were raised from 537°C to 600°C. As a result, it is projected that the modernization will enhance the unit's net efficiency up to 42.9 percent, reduce CO_2 emissions by more than 10 percent, lower the coal consumption by more than 10 percent and extend the major inspection interval from six to twelve years for new upgraded components. This is an example of Siemens Energy commitment to provide our customers with solutions which bring their assets to an optimum level. Chinese customer will now benefit from significant increases in generation revenue and reduction of maintenance costs.
Siemens Energy supplied all the components required for the modernization. The scope of supply included new rotors, blades, inner cylinders, main stop and control valves with new high temperature inlet sleeves, main steam piping and the installation of two new High Pressure (HP) steam extraction from the High Intermediate Pressure (HIP) turbine. This includes a top heater extraction for lower part load operation and high part load efficiency for steam cycle optimization. The customer approved contractors performed all the work on the boiler and other auxiliaries.
Siemens Energy applied their state-of-the art technology that incorporates advanced control stage, blading designs (3DS and 3DV) and advanced sealing technology. The combination of these products enables the highest efficiency to

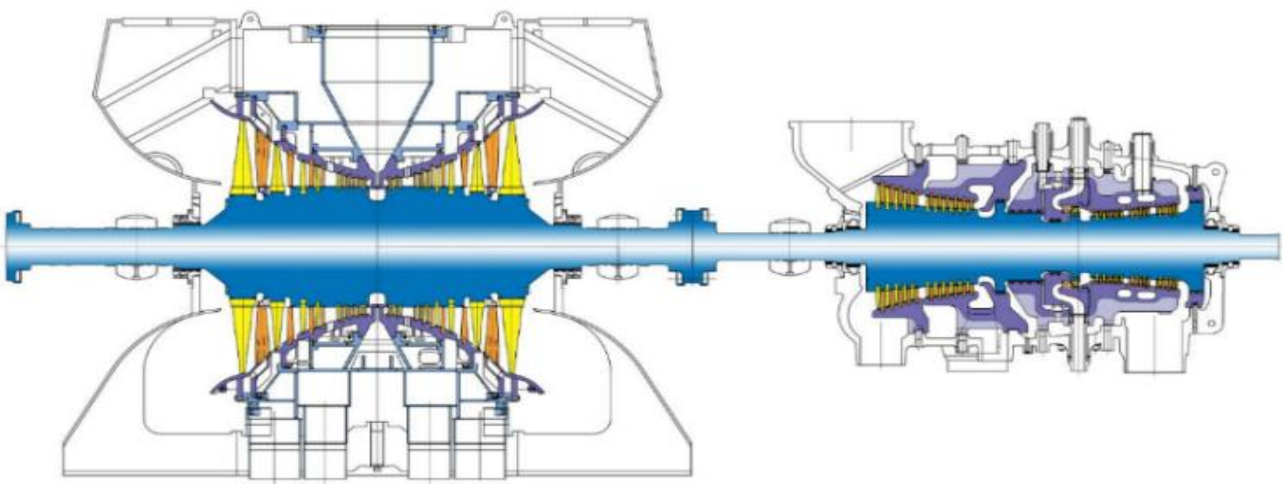


Figure 1 Mods & Upgrades summary & carbon footprint reduction

be attained with flexible load operation and shall minimize the degradation for sustainable performance for the years to come.
In addition to the inspection of the retained components to ensure suitability, the interfaces between the new and retained components have been restored to meet or exceed the original design criteria that enable the unit to be returned to like new condition. This ensures maximum performance and sustainable operation going forward as China's power producers are facing the challenge of increasingly strict requirements for energy efficiency and CO_2 emission control.
This modernization project is another example for the domestic Chinese and Global market that demonstrates that Siemens Energy has solutions for all of the key drivers, important to our customers such as increased generation revenue, efficiency, output along with environmental impact, fuel and maintenance cost reductions.

5 Modernization of Steam Turbines for "Mods & Ups Market" in India

The steam turbines were originally designed by Siemens Energy and LMZ and were manufactured primarily by BHEL based on a license from Siemens Energy (KWU) and LMZ. They consist of a single-flow high-pressure steam turbine (HP), a single-/double-flow intermediate-pressure steam turbine (IP), as well as a double-flow low-pressure steam turbine (LP) running at full speed (50 Hz). The axial exhaust area of the LP flows varies from 5.0 m² to 10.0 m² depending on the turbine frame. The technology of these steam turbines was developed in the 1970s and 1980s, and Therefore a high potential exists for improving turbine efficiency and eliminating design weaknesses.

In the area of efficiency improvements, large strides were made by steam turbine suppliers in the 1990s, such as three-dimensional blades, advanced sealing, and optimized flow paths. This was possible through the introduction of advanced CFD methods and enhanced manufacturing capabilities like multiple axis milling machines for three-dimensional blades.
At that time, Siemens Energy developed a new blade design for HP and IP drum stages called 3DS™ (three-dimensional blades with reduced secondary losses). In contrast to the classical cylindrical design, the single blade shows a highly three-dimensional airfoil shape that is twisted, tapered, and bowed. Each radial profile section is optimized numerically to ensure the highest profile efficiency. The bow design at the hub and tip sections ensures that secondary

KWU 200 / 210 MW	HP	H30-25
	IP	M30-25
	LP	N30-2x5m²
KWU 500 MW	HP	H30-63 H30-100
	IP	M30-50 M30-63
	LP	N30-2x10m²

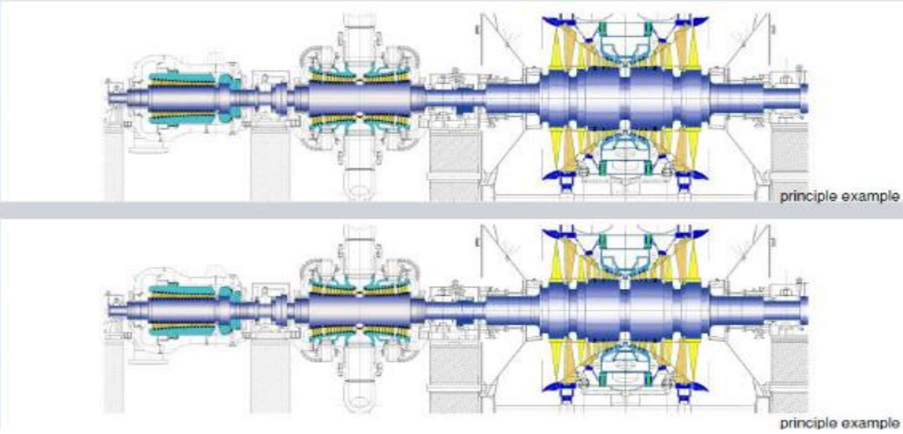


Figure 2KWU Steam Turbine upgrade scope for Indian Market

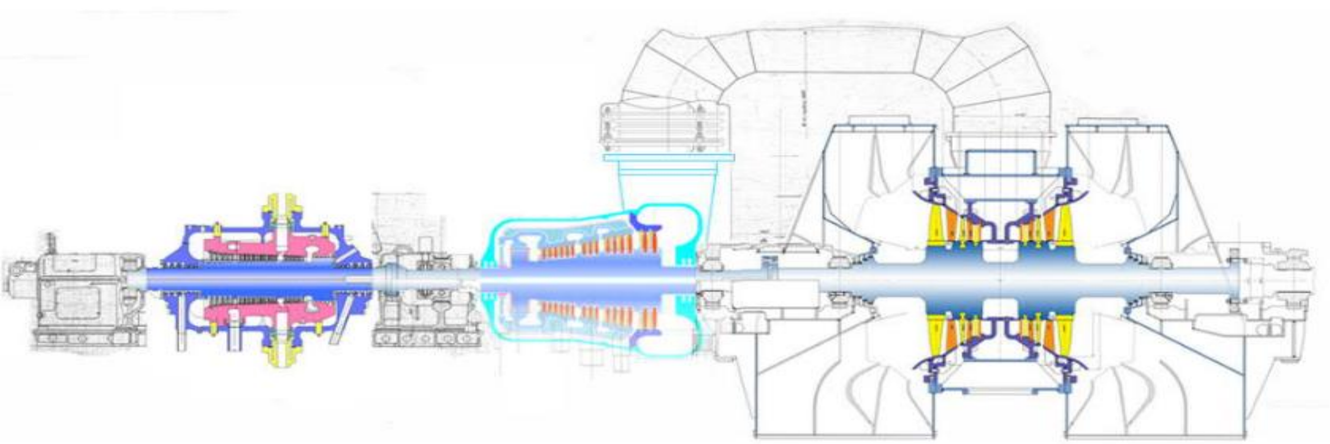


Figure 3 LMZ Steam Turbine upgrade scope for Indian Market

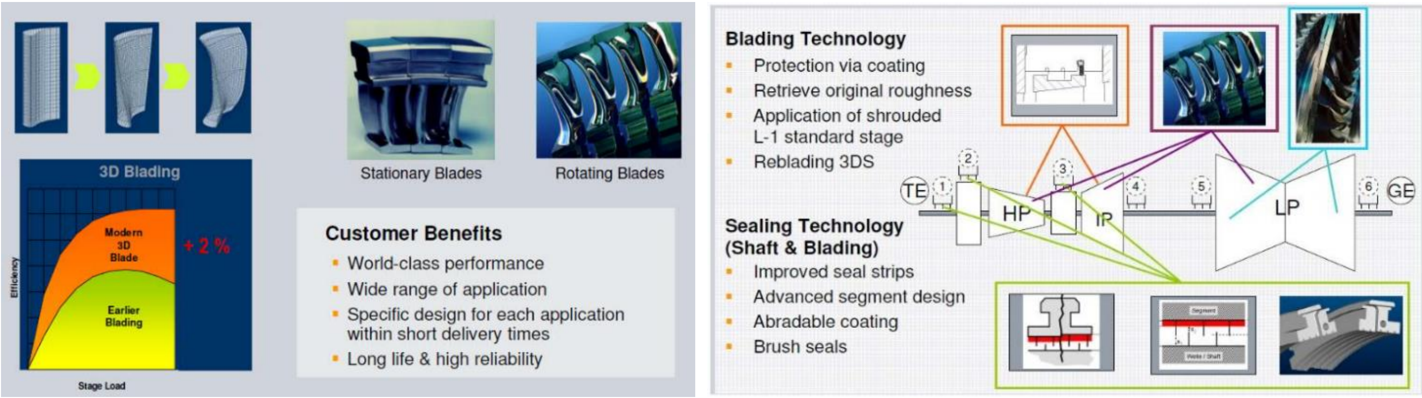
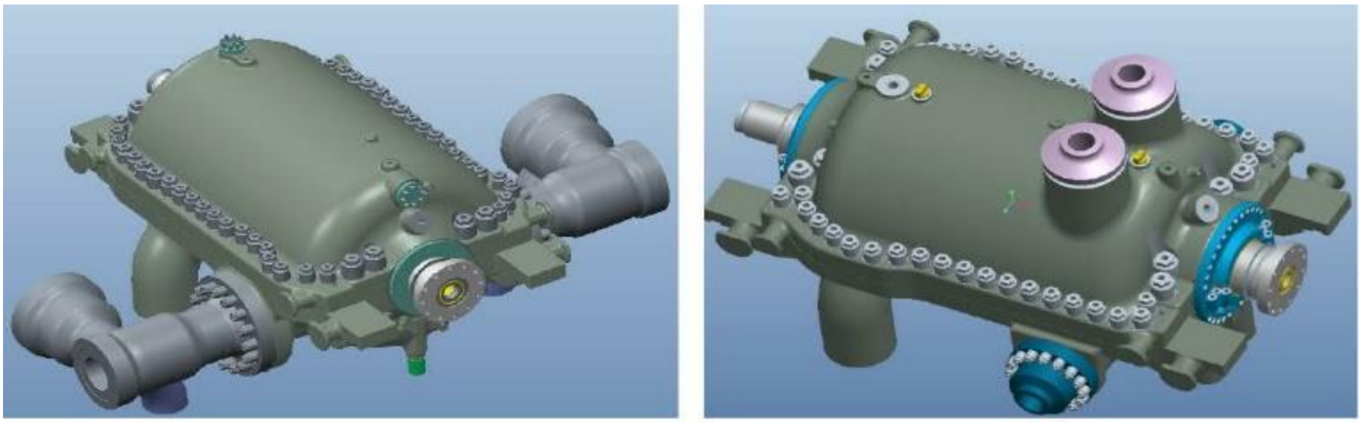


Figure 4 Efficiency Improvement Technologies (Examples: State-of-the-art 3DSTM blading & sealing technology)

losses are minimized through an improved load distribution. In addition to the aerodynamic optimization, a verification of all mechanical stresses is performed with advanced tools and methods [3].
Additionally, to the blade optimization, a blade path optimization is conceivable when multi-stage blade paths are considered as they occur in HP and IP steam turbines. Siemens Energy developed such an optimization method called 3DV™ (three-dimensional blading with variable reaction) whereby more than 80 variables (for example, stage reaction, blade height) and more than 300 constraints (for example, channel and mechanical limits) can be managed automatically. Blade path designs (classic approach) where stage loading and stage reaction were input parameters, now those parameters are the results of a numerical optimization method. Applying the existing boundary conditions as numerical constraints and optimizing the load and reaction distribution of the blade stages yields maximum turbine efficiency [1].
Advanced seal systems reduce tip clearance losses and therefore improve efficiency, especially in high-pressure and intermediate-pressure turbines where the radial gap is large relative to the blade length, leading to relatively high tip clearance losses.

6 New HP module & valves

The new HP module consists of a new rotor, a new inner casing and outer casing mounted on existing pedestals and new single-flow reaction-type blade path design. Options with control stage design or overload admission are available based on loading and flexibility requirements. The rotor design is a mono-block type without a through bore. 1% or 10% Cr (as necessary for thermal upgrade) is used for the inner casing. The blade path design uses the above-mentioned Siemens Energy technologies of 3DS™ and 3DV™. New advanced sealing methods, including the well-proven seal strip design and sealing segments with abradable coating, will be applied as necessary. Main inlet valves and overload admission valves are used from standard Siemens Energy product line and these can be accommodated without major rework to existing foundation.



Outer casing FA design

Outer casing PA design

Figure 5 HP upgrade variants (LMZ)

7 New IP module & valves

The new IP inner module consists of a new rotor, a new inner casing, a new integral outer casing and a new single-flow reaction-type blade path design. The rotor design is a mono-block type without a through bore with 1% or 10% Cr (as necessary for thermal upgrade) is used for the inner casing and rotor. The turbine can be mounted on existing turbine pedestals.
The blade path design was made with the mentioned Siemens Energy technologies of 3DSTM and 3DVTM. New advanced sealing methods, such as the well-proven seal strip design and sealing segments with abradable coating, will be applied as necessary. Siemens Energy reheat valves are used at the inlet of the IP turbine. The valve upstream piping and downstream admission pipe loop is adapted to avoid any rework on existing concrete foundation.

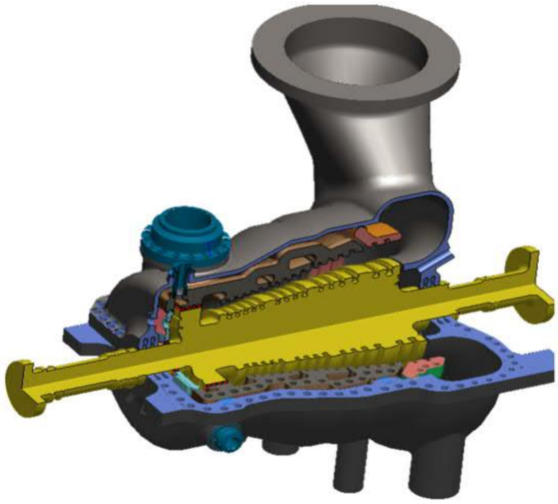


Figure 6 IP upgrade overview (LMZ)

8 New LP inner modules

Siemens Energy upgrade packages for low-pressure (LP) turbines in fossil-fueled power plants consist of a single-piece (two halves) inner cylinder, a double-flow rotor with a fully integral no-through-bore design, and high- efficiency stationary and moving blades. The last-stage blades have individually optimized profiles and are made of high-grade steel. To reduce exhaust losses in the LP turbines, the exhaust areas of the low-pressure turbines can be favorably adapted to the present backpressure, for example, by increasing the last stage from 5m^2, up to 10m^2 (based on LMZ/KWU upgrade, as applicable).

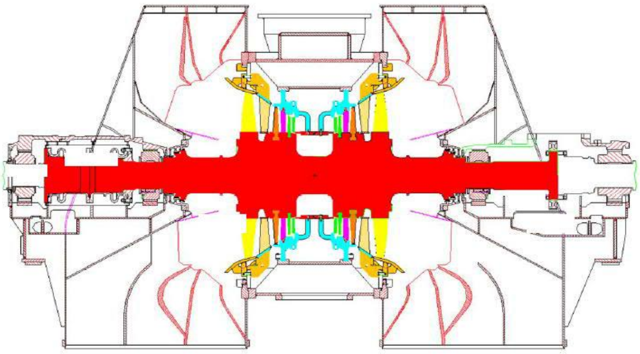


Figure 7 LP upgrade overview (LMZ)

The Siemens Energy LP turbine upgrade packages are designed for optimized steam flow through high-efficiency blade profiles, minimized clearance losses, and reduced exhaust losses through increased exhaust cross-sections. Additional features of the packages include:

- Upstream moving blades (including L-2) are integrally shrouded reaction-type blades with T-root design.
- L-0 moving blades are freestanding or inter-locked integrally shrouded blade design (as and where applicable) with side-entry root design.
- L-1 moving blades are interlocked integrally shrouded blade design, with side entry/T-root design.
- Erosion-protection features including flame hardened L-0 moving blades, moisture-removal features, improved materials and coating, as needed, to reduce water droplet erosion.
- All new replacement inner cylinder and stationary blade path components, blade rings with support and alignment hardware.
- Optimized exhaust-flow guides, sealings on shrouded blades for reduced tip clearance losses, Inlet flow guide.
- New coupling bolts, keys, and assembly hardware.

LP inner casings can suffer from erosion-corrosion and low-cycle fatigue after long-term operation if not properly designed. Based on experience the selection of proper materials for inner casing components has eliminated the erosion-corrosion problems [1].

9 Steam Turbine modernization project examples

Siemens Energy Service has successfully modernized more than 300 steam turbines (fossil and nuclear, low-, high-, and intermediate-pressure turbines) around the world. In addition to the Siemens Energy fleet (including KWU, Westinghouse, Parsons units) there have been proven modernizations conducted on other OEM units, including Alstom, MHI, and LMZ turbines. The list of LMZ modernizations includes the K200 (example Ostrolenka, Poland) and K300-MW (example Syrdarinskaya, Uzbekistan).

10 References

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