

PERFORMANCE INCREASE THROUGH WORLD CLASS TECHNOLOGY AND IMPLEMENTATION

by

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INTRODUCTION

In the present power production market, maintaining an economically competitive power plant requires the latest technological mechanical improvements, as well as efficiency optimization and increase economics of operation and maintenance. Through present day technological developments, the ability to improve economics through increased performance, life extension, and reduction of maintenance costs is, in many cases, just what is required to remain competitive. In addition, the increased pressure to reduce environmental impacts will continue to force the power industry to develop and apply more complex technologies to existing power plants. Since the ratification of the Kyoto Protocol in February 2005, the CO₂ impacts has become an additional driver to improve plant efficiency. The goal of 8% greenhouse gas emission reduction by 2012 will require continued development of new technologies as well as applying the present modern technology to older, operating power plants. The contributions of the Turbine upgrade for the Mehrum project saves the emission of over 135 000 tons of CO₂ gas emissions per annum which will put this facility in a good trading position for the up coming start of CO₂ Credit trading.

The turbine being one of the major key components in the power plant, is clearly one of the areas where the largest improvements can be made in plant efficiency, thus enabling environmental/economical operating improvements. In the Mehrum project, technologies developed in recent years for the new apparatus business were used to bring the operating levels up to par with a present day power plant technology. Specific efficiency improvements can be created through an elaborate design process. This process specifically targets items such as turbine blade path and essentially includes engineering calculation, flow path optimization, mechanical design and manufacturing under given the specification and constraints of the existing plant equipment and the end-users requirements. Other advantages gained in the elaborated design process include lifetime extension and enhanced operating features made possible through present day design and engineering tools, such as Finite Element Analysis, as well as new metallurgical findings.

The ability to design a Turbine upgrade in an existing facility, to manufacture and implement this design and erect the new turbine in an economically attractive project is the challenge. This paper describes in detail the technology and how this is applied and executed in the case of the coal-fired Mehrum Power Plant, Germany.

CUSTOMER NEEDS

Customer Needs – Economical Motivation Of Major Upgrade Technologies

For power producers it is important to operate their equipment with the best possible performance, especially with respect to efficiency, reliability and operation flexibility, in order to be competitive in the power market itself. Furthermore it is necessary to meet or surpass the environmental requirements, especially regarding CO₂-emissions. Apart from meeting these requirements, the CO₂-emission certificate trade has a high potential market for the near future. Therefore power plants will be employed by power suppliers based on their efficiency and thus their cost effectiveness.

For modernization & upgrade applications in particular, very short realisation times are important as well as high flexibility in implementing new features in existing machines by taking into account fixed boundary conditions: thermodynamic requirements, mechanical demands, and geometric limitations.

Overall Plant Performance

Overall plant efficiency is one of the key parameters to express the cost effectiveness of a power plant. It is mainly influenced by the boiler and the steam turbine island as they are the main components and thus have the largest impact on the overall thermal cycle. The combination of both systems gives an expression of the plant heat rate.

$$HR_{plant} = \frac{HR_{turbine\ island}}{\eta_{boiler}}$$

Since the steam turbine has such a big influence on the overall power plant effectiveness, great efforts need to be made to increase performance with respect to different features:

- heat rate / efficiency
- life time
- operational behaviour procedure / start up time

Evidently the most important parameter for base load operation is efficiency. The improvement of Siemens steam turbine plants with regard to heat rate development over the last 30 years is shown in figure 1. Siemens has developed a substantial number of new technologies through the whole process including engineering, manufacturing and implementation of new products according to customer needs.

Improvement Of Heat Rates Within The Last Thirty Years

Based on wide experience and feed back from a large number of running machines together with R&D programs and testing, significant changes in design have been implemented and thus a continuous improvement reached.

Heat Rate Improvements in large extent achieved by Advanced Blading Design from Cylindrical Profile Optimization up to current 3DV Blade Design and Advanced LP Blading Design

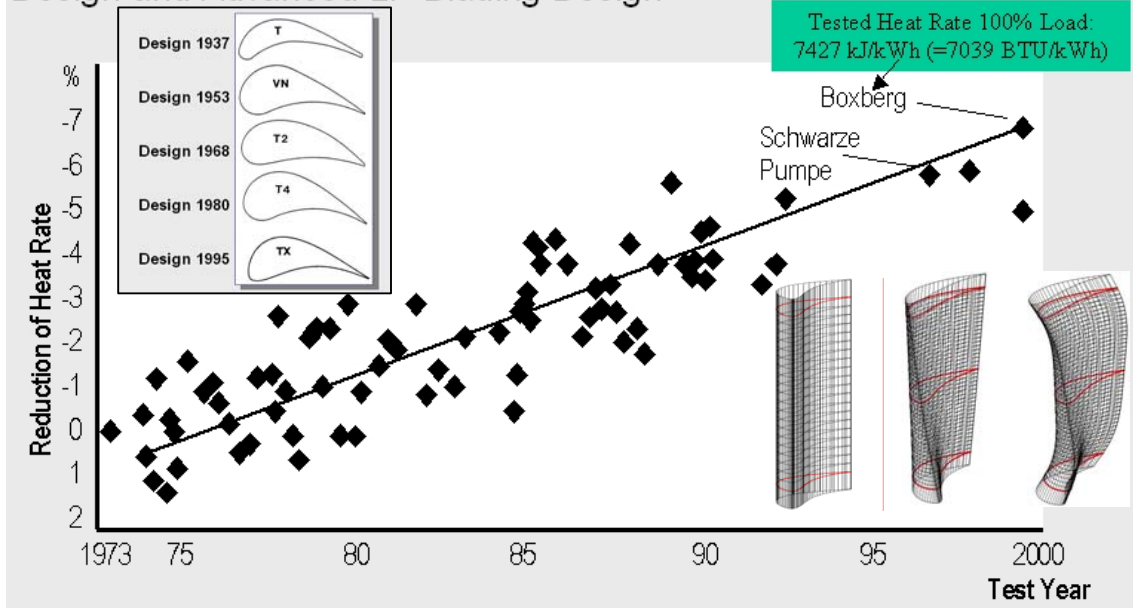


Figure 1: Trend of heat rate development over the last 30 years

The most significant achievements of this development were two conventional lignite-fired power plants in Germany (Boxberg, Niederaußem) which displayed a turbine heat rate as efficient as 7427 kJ/kWh at Boxberg.

The basis for such improvements were the creation of new blade design as the heart of the turbines, as well as substantial optimisation in other turbine areas such as sealing and flow path determining components like valves, inlets, and outlets.

NEW RULES AND TOOLS

Blade Path Design System

For the most important component determining the efficiency of a steam turbine, namely the blade path itself, a very sophisticated design system was developed. The main points of this developing process relevant to modernisation applications will be described below.

In recent years a complete new design system was developed by Siemens combining all necessary calculations according to the given boundary conditions. Based on the desired thermodynamic parameters such as pressures and temperatures in front and behind the turbine, as well as required mass flows, an optimised blade path is calculated using a CAE tool. The calculations consider all requirements with regards to thermodynamics, aerodynamics, mechanics as well as complex geometric boundaries and limitations. Especially the latter is a big advantage for modernization & upgrade applications since the new blade paths must be fitted into the existing turbine cases. During the design process each blade contour is optimised using an objective function for the best efficiency. The numerical

calculation is based on more than 200 variables with 1000 constraints, such as mechanical restrictions and limitations, per blade path resulting in a complete 3 dimensional blade design.

The results are transferred automatically into the appropriate CAD tool which creates the drawings such as blade and groove plan later on. In addition all necessary information is handed over to the appropriate CAM process. The whole process is very time efficient and leads to best results.

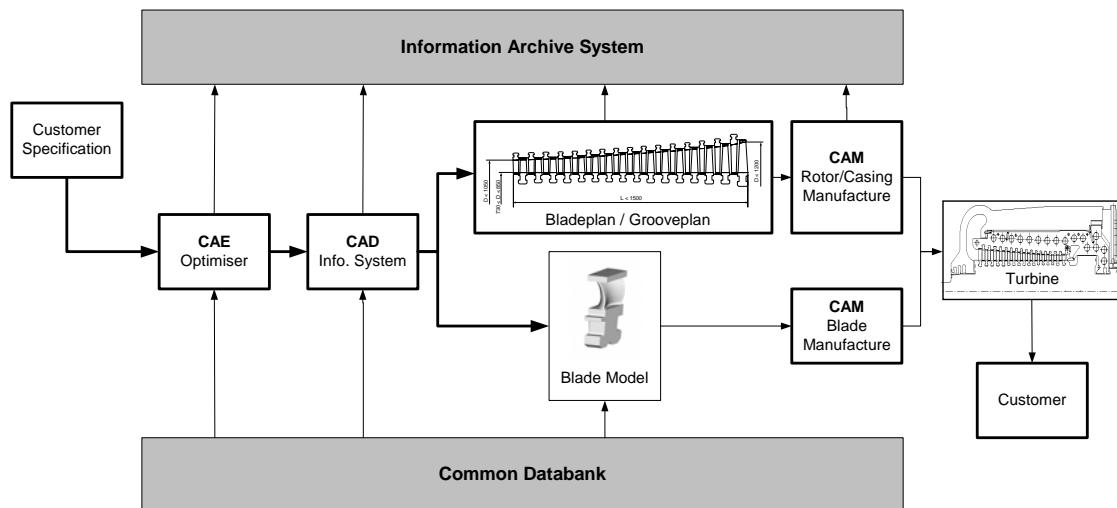


Figure 2: Overview of blade design & manufacturing process = so called “3DV-chain”

During the development of the design tools high attention was paid to maintaining internal standards regarding calculation rules, while giving as much freedom and flexibility as possible to the designer in order to adjust the new blade path to get the best possible efficiency.

By using the new features for optimising the blade path it is possible to react to changes in the plant performance which might come to light during recent operational experience. For example the swallowing capacity of the partial turbines can be adjusted in order to pay attention for possible changes in steam cycle. Variations in behaviour of the steam generator such as higher capacity than expected or degradation of steam generator can be taken into account. Consequently, restrictions of main steam pressures can be kept, even while increasing the main steam mass flow in case of large steam production capacity of the boiler. Also, changes in the desired cycle, like different extraction conditions because of changing the existing plant topology, can be taken into consideration by optimising the complete blade path.

Finite Element Analysis

The whole turbine can be modelled using Finite Element Analysis (FEA) in order to improve the prediction of the thermal and mechanical behaviour. Thus the clearances can be reduced to a minimum allowing safe operation with minimum steam loss. Furthermore the calculations allow detailed investigation regarding lifetime analysis. Using steam temperatures and pressures as boundary conditions the stresses in the turbine components can

be predicted. Considering the thermal parameters the geometry can be optimised and varied in order to reduce these stresses under operating conditions, and thus the life time can be maximised.

Also transient operations, such as start up procedures, can be optimised by using the FEA in order to reduce start up times and enhance the turbine availability.

NEW PRODUCTS

For the purpose of the performance improvement Siemens has developed a number of different products which can be applied to all kinds of steam turbines.

3DS / 3 DV Profiles

Based on results of long development programs a new generation of profiles characterized by a completely three-dimensional design were created. In a first step, the so-called 3DS™ blade was developed. This blade was designed specially for use in front stages of HP and IP turbine models and was targeted to substantially reduce secondary flow losses. Detailed experimental investigations performed on a 4-stage close-loop model turbine under representative Mach and Reynolds numbers showed that a stage efficiency improvement of up to 2 percentage points can be achieved with these 3DS™ blades in comparison to conventional blades.

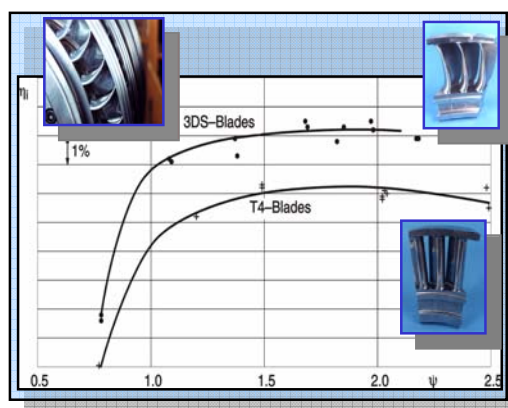


Figure 3: Efficiency increase

This benefit of employing 3DS™ blades has been confirmed for a multitude of real steam turbines in new apparatus and major upgrade applications. The most prominent example is the steam turbine power plant Boxberg (907 MW) which is a large conventional lignite-fired power plant. Here, internal efficiencies of 94.2 % and 96.1 % for HP and IP cylinder respectively were measured.

In order to adapt the profiles to the best possible steam flow conditions and to reduce the overall losses of the profiles the contour of the blades is optimised stage by stage. Apart from minimising the profile loss itself, as well as decreasing the hub and tip losses, further design parameters can be varied during the blade layout process. The most important are the degree of load distribution between the guide and the rotating stages and the stage reaction. In a second major step this new technology has led to the so called 3 DV™ blade profiles. The exploitation of these additional free parameters yields further efficiency improvement by up to 1 percentage point in cylinder efficiency. The new 3 DV™ Technology was first applied to the world's largest super-critical lignite-fired power station, Niederaußem (1000 MW). Since then, it has been employed in all new machines and the majority of upgrade projects.

This gives another big advantage as it reduces the necessary installation space. This of course is an essential point for modernisation applications as it is necessary to fit the geometric boundary conditions which are given by the existing machines.

HP And IP Turbine With Low Reaction Stage

For the HP and the IP blade path a low reaction stage can be implemented. That means the first guiding blade row is designed as a complete ring and not as a conventional stage design using shrouded blades. It combines several advantages. Because of the fixed connection between the guide blades and the inlet ring there is no seal flow across the first guide blades which then allows for improved efficiency. Furthermore because of the high physical loading of this first stage the load coefficient for all of the remaining drum stages is reduced. This gives more geometrical freedom in terms of space for designing the drum stages and leads to a shorter drum length or to the possibility of adding more stages. Another advantage to the inlet ring design is the lower temperature seen by the rotor. This results in a longer life time because of a lower inner shaft temperature which reduces creep stresses and embrittlement.

EXAMPLE: 705 MW Lignite-Fired Power Plant Mehrum, Germany

The Mehrum Power Plant is a large, conventional, hard coal-fired plant equipped with a once-through Benson boiler. The Steam Turbine consists of 1 HP, 1 IP and 2 double flow LP turbines, designed for a rated power output of 705 MW. After almost 25 years of successful operation it became an object of interest for a complete retrofit due to the availability of new technologies and techniques for the main component, which is the steam turbine. The fit with the existing hardware was excellent, offering great benefits. Because the outer casings were not stressed up to their material limitations the retrofit philosophy of changing all internal parts was applied. Therefore the rotors and inner casings of all partial turbines including the blades were replaced. The result was a complete new turbine in an “old coat”. It combines a lot of advantages of modern technology with regards to efficiency, life time and overall performance with an excellent adjustment to an existing plant topology. For example during this retrofit a heat recovery system for combustion air preheating was also installed which changes steam extraction conditions. Also at the “cold end” substantial improvements in the cooling tower area were carried out, improvements which could be converted efficiently by the newly enlarged LP end stage.

The steam turbine consists of an H-M-N turbine with steam parameters of:

Main Steam Pressure:	191 bar	Main Steam Mass Flow: 580 kg/s
Main/Reheat Steam Temperature:	530 °C / 530 °C	Cond Pressure: 0,0575/0,0863 bar

First Commissioning: 1979

Modernization: 2003

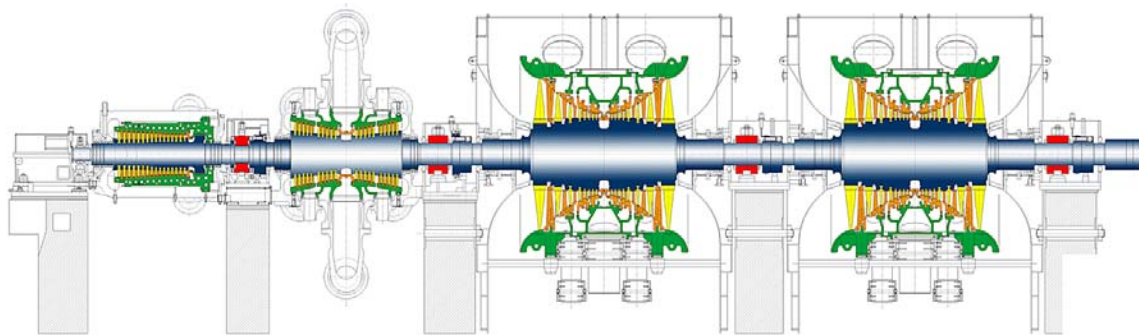


Figure 4: Cross section drawing of Mehrum Steam Turbine – all coloured parts were exchanged

Scope of the complete modernization project for Mehrum contained the following parts:

HP turbine		IP turbine		LP turbine	
Modification	Purpose	Modification	Purpose	Modification	Purpose
New rotor with 3 DS blades	Efficiency increase, life time extension	New rotor with 3 DS blades	Efficiency increase, life time extension	New rotor, new blades, 8m ² last rotor blade	Efficiency improvement, life time extension
New guide blade carrier with 3 DS blades & low reaction stage	Efficiency increase, life time extension	New guide blade carrier with 3DS blades & low reaction stage	Efficiency increase, life time extension	New guide blade carrier	Efficiency improvement, life time extension
Shaft sealing segments with spring back seals	Improving operational behaviour	Spring back seals in shaft sealing area	Improving operational behaviour	New diffuser	Reducing leaving losses thus improving efficiency
Re-machining of HP casing	Life time extension, new start up curves, optimisation of streaming contour			Stream Optimised Inlet area	Efficiency improvement, life time extension
HP vent pipe	Avoiding overheating of blading			New inner casing	Adjusting of size to accommodate longer blades and Allowing factory preassembly to shorten outage time

Figure 5: Scope of complete modernization project for Mehrum Steam Turbine

HP Turbine: H30-63-2:

For the HP turbine a complete new blade path was designed taking the advantages of the CAE tools. All stages were designed as 3DS/3DV blades. The interaction of the stages was adjusted to the newly implemented low-reaction stage in the front of the blade path. By varying the stage load an optimum stage number could be achieved, while reducing the secondary losses of the blades.

In the second part of the HP drum the shaft was designed with a negative surface gradient. This gives the opportunity to increase the effective exhaust area thus optimising flow conditions as well as exhaust losses, although outer diameter was restricted by maintained outer casing.

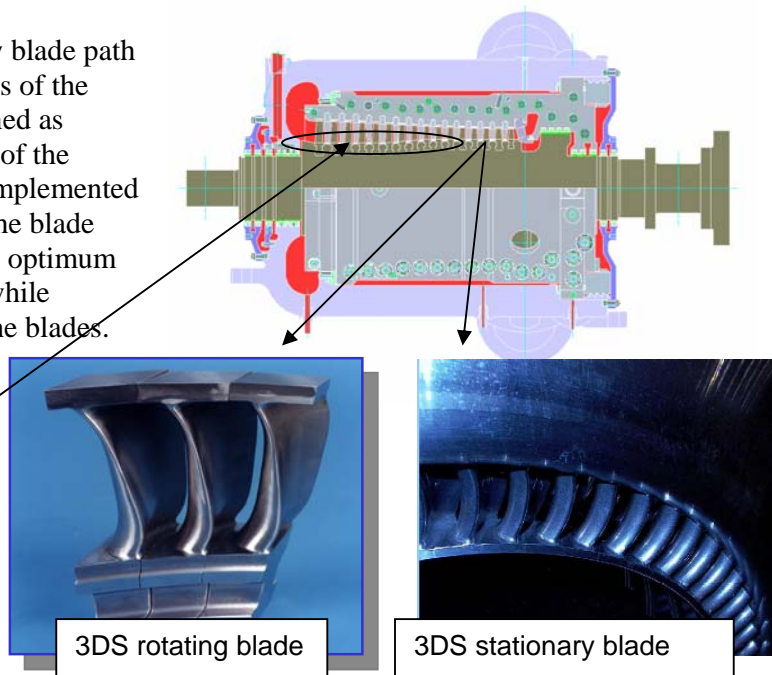


Figure 6: 3DS blading in the HP turbine

Furthermore using a newly fashioned 3 dimensional digitally programmed machine tool the inner surface of the casing in the exhaust area was machined. A substantial amount of material was removed in order to eliminate a thin layer at the surface which contained areas of high fatigue conditions. By doing so it was possible to optimise the exhaust topology in order to have a continuous area increase as well as an extension of outer casing lifetime.

IP Turbine:

The blading of the IP turbine was changed from the old fashioned T2 profile to the state-of-the-art 3DS profile. Again the drum stage design was adjusted to the optimum interaction with the low reaction stage. Also here the advantage of reducing the surface temperature of the shaft was taken. This has positive effects in respect to life time apart from the efficiency improvement. Furthermore the inlet area was optimised regarding to contour as well as dimensions in order to achieve optimal flow conditions.

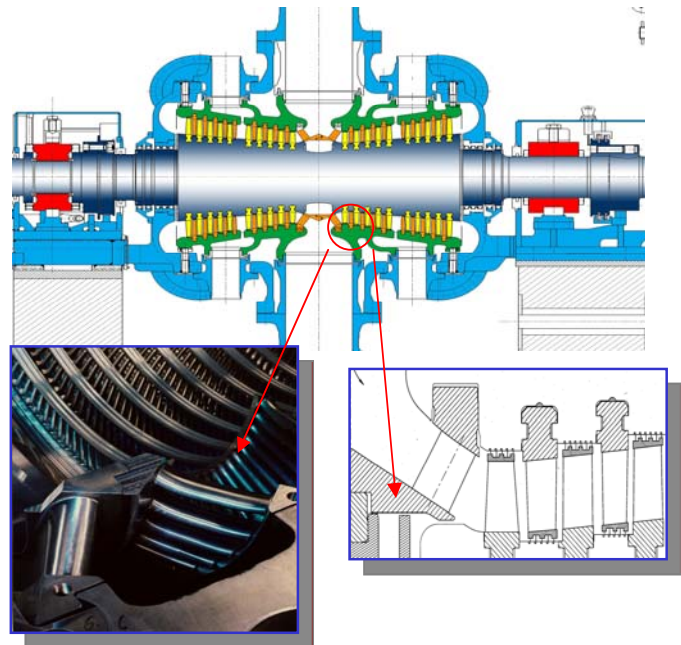


Figure 7: IP turbine blading

LP Turbine:

The main improvement of efficiency in the LP turbine is caused by the larger exhaust area. The old 6.3 m² last rotor blade was replaced by an advanced 8 m² LP end. The exhaust losses were thus be reduced significantly. In addition the diffuser was optimised to the new geometric conditions. In conjunction with the new condenser conditions resulting from the cooling tower modifications an additional power increase was achieved by this LP modernisation.

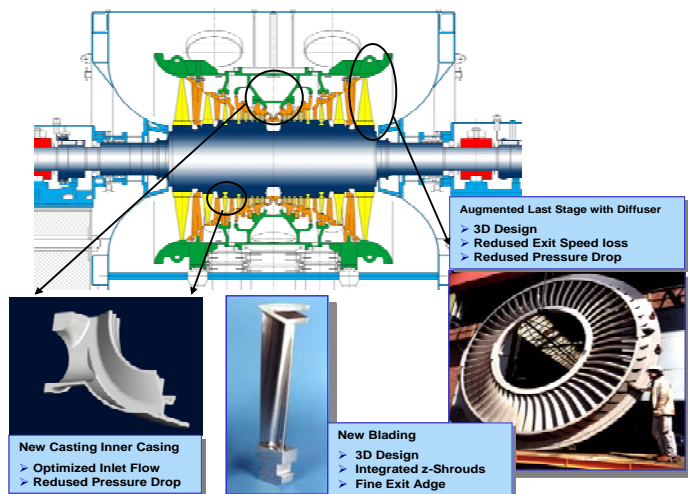


Figure 8: LP turbine improvements

Dimensions of LP end stage

Old
New

Length of last rotor blade

827,0 mm
914,5 mm

RESULTS

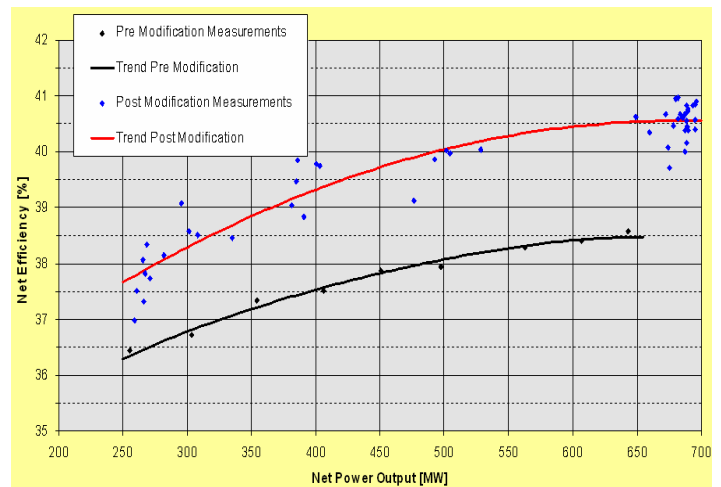
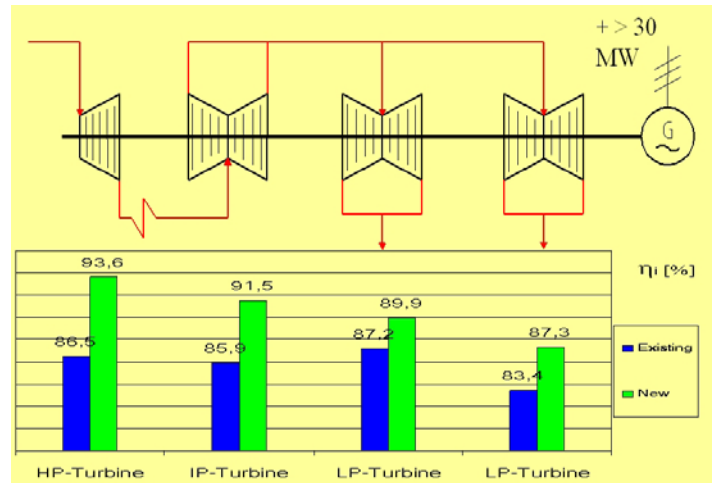
After the installation of the new turbine measurements of internal efficiencies of HP and IP turbine took place and showed very good results.

After completion of the whole upgrade project in summer 2003 the load factor rose to 70 % and even higher afterwards. The overall plant efficiency has risen from 38.45 % to 40.45 %, with a saving in carbon dioxide emissions of 193 000 t per year. The reduction cost is estimated at around 5.6 euro/tCO₂, discounted over 20 years, assuming an output of 3500 GWh/year.

The main part of the electrical megawatt increase – compared to the same thermal power – is contributed by the steam turbine, estimated at around 30 MW. About 4 MW are estimated to result from the cooling tower upgrade and 6.5 MW from the flue gas heat recovery system.

On the basis of these good results the Mehrum Power Plant can look optimistic in the near future of CO₂-emission trading age.

Picture 9: Efficiency Increase due to retrofit



Picture 10: Efficiency Increase versus Electrical Load

PROJECT IMPLEMENTATION

What is meant or understood by project implementation? A more familiar concept for this is simply Project Management, or formerly stated, a single person or group of persons who's entire task is to insure that the overall task is done with 3 important things respected; namely time, quality and cost.

Considering the technology gains the past 30 years, the competitive gap between old and new power plant economics has widened considerably. It has led many older plant operators to begin considering the possibilities, such as improving economics through plant upgrade, modernization and/or life extension, or alternatively to shut down the operation down.

Considering a modernization, it is one thing to have access to leading edge, economically feasible technology, it is just as critical to implement and apply this technology in an

economically feasible manner. The famous saying; “Time is money” is nothing new to the industry, but when the outage costs are weighed with the MW improvements created by a plant modernization, one quickly realizes that the best performance improvements can quickly become economical nonsense if not implemented properly. As an example, the lost revenues due to a one day outage extension can easily consume months of performance benefits achieved through heat-rate improvements.

Realizing this balance between having leading edge technology, and being able to implement it, it becomes clear that without well thought-out planning, and performing during the project implementation phase, project economics can be quickly impacted to the extent where the project loses in meaning and value.

Specifically, as well as in the case for the Mehrum Project, the implementation of performance increase, or *Modernization*, offers various challenges significantly different to that of a new EPC power project, making implementation key.

THE CHALLENGES

The implementation benchmark has always been the comparison to “Greenfield” type projects, also known as New power development projects. There are, however, challenges which make the implementation of modernization/upgrade projects significantly more complex. For example, in many cases owner/operators of 25 year old power stations, are generally having to contend with remaining competitive or shut-down the operation. In some cases the focus is prematurely the shut-down option rather than extending the life due to the existing operating and maintenance economics of the power station. Such a “close-ended” strategy (no further capital investment in the facility) adversely affects the condition of existing equipment and the increases the investment required in balance of plant, control systems, structures and surrounding areas to make a turbine modernization worthwhile. In the case with Mehrum, the plant had been operating since 1979 and had seen almost 4000 start-ups during this time. Despite this, the owner desired continuing the operation of the unit to 2020 and possibly beyond.

This situation requires that a thorough assessment be made, where records, customer interviews and physical inspections are required to as accurately as possible measure the compatibility and survivability of the plant as a whole, not just a turbine modernization. This assessment and given the quality of plant operation and maintenance records and documentation, also allows a rough estimate of the engineering, or “Re-engineering” of balance of plant systems (BOP) required to do the turbine upgrade successfully. This assessment and economic modeling in many cases assists in determining the attractiveness of keeping older power plants in operation.

Once the decision to modernize is made, the next significant challenges are the interfaces between old and new BOP systems, as well as the existing physical restrictions for items such as “lay-down” areas, staging areas, usage of existing cranes, structural interferences, etc. Where New Plants can be erected without constraints, a modernization project always requires dealing with the existing restrictions.

As there is no time for surprises during the erection phase, incompatibilities between the old and new equipment need to be addressed in advance of the erection so that the all important schedule is maintained. Where particularly critical conditions are evident, computer models assist in developing and testing, through thorough simulation, the necessary erection sequences well in advance of actual outage.

The final major challenge is when the actual outage begins, the work begins, the clock begins ticking, the machine is opened and the unexpected occurs. It is here where the experience and preparedness is of the utmost importance. The reaction time to assess findings, decide how to proceed, design a solution, acquire the necessary tools and materials and implement is where only experience can avoid major delays.

When to Begin the “Implementation” Phase

Relative to “Green-field” power projects, (also known as *New Apparatus*), such modernization projects are realized in significantly shorter time periods. This due to various reasons such as stability (or instability) of fuel costs which impact the economics of the project, the requirement to retire old equipment due to indications of material stress, extension of plant life, etc. Where a standard 600 MW new apparatus EPC project may take upwards of 4 years of execution, the modernization, of such a turbine/generator plant must be realized, as was the case with the Mehrum Project, in as little as 24 months after contract commitment to support the end-user needs and be economic viability.

This challenge requires that the actual “Implementer”, or project manager be on board several months prior to project effectiveness, or *Project Award*. Having the nominated PM involved before official project begin is partially required to fulfill schedule requirements, but is also a key element to interfaces with other parties, offers several advantages to the project, and supports the customer satisfaction.

In most cases a modernization project requires extensive engineering to insure that the proper fit of the new equipment is insured from both the mechanical and process parameters. This work needs to be well developed prior to the procurement of long lead time material orders for items such as forgings and sub-system design. As the manufacturing processes and location is the same for Modernization and New apparatus projects, a manufacturing window must also be insured well in advance of the actual manufacturing process. By getting an early start on these activities, the possibility of executing short project schedules with minimal risk is insured, and the financial benefits to the end-user made possible.

From the plant owner perspective, establishing contact and beginning work with the contractor is of equal importance as the engineering/procurement effort for owner supplied BOP partners also requires interfaces to be defined as soon as possible. Plant outages where Turbine/Generator modernizations take place are generally categorized as “Plant Overhaul” outages where more time is allocated for major maintenance items, such as at Mehrum, major cooling tower re-work, and additional heat exchangers in the fluegas path. This means that the number of different contractors, activities and interfaces are higher and more complex compared to a normal yearly maintenance outage. Particularly in cases where the end-user is unfamiliar with the contractors methods and designs, the earlier the lines of communication are established, the less chance that misunderstandings of scope, design and erection sequence arise.

It is proven that the earlier involvement between Customer and Contractor the more successful the projects have been, and the highest level of satisfaction, both in the execution and the results, is reached. Despite having over 70 workers on working strictly on the turbine retrofit, the coordination worked well and the aggressive schedule for all work was met.

Execution Milestones/Monitoring

Macro

Once a project is officially awarded a solid foundation for internal execution has already established and it then becomes possible to formalize the control or handling of key items amongst all contractors and the customer. The highest priority is given to all forms of communication. In this day where mobile phones, e-mail and websites are the norm, establishing a common set of rules for communication, and having the discipline to execute accordingly is critical. Exchange of Organizational structures and setting up specific review procedures and review meetings as early as possible also best serves both contractor and end-user.

Such items are best addressed in a Project Handling Manual (Project Handbook) which in addition to communication, further addresses items such as schedule, binding documents, witness points, meetings, reporting, drawing review process, drawing turn-around times, etc. This is most effective when agreed upon by all interfacing parties. What is also most valuable is that such a manual insures smooth adaptation of contractors whose participation first starts well into the execution of the project (such as transportation companies, erection sub-contractors etc.

During discussion of the final contract terms it is always important to establish monitoring points where the progress and quality of the manufacturing is jointly visited by both the contractor and end-user. Such milestones, or witness points offer a chance to finally see the pieces coming together, and further sensitizes the realization of the project. During such times a general appreciation for the complexity of the project is created, further building on a cooperative and goal oriented attitude. The 37 customer witness points for the Mehrum project gave ample opportunity to have regular review and dialogue of the progress of both manufacturing and delivery.

Micro

Internally, the first step is getting the necessary information in the hands of the people doing the work! This takes the form of a kick-off meeting, where all of the associated departments, and department heads, are invited for both a presentation and question and answer period. Preparations for this meeting are done with the agreement and participation of Marketing, Sales and the Project Management department in advance so as to insure that all developmental aspects and intricacies of the project are properly represented.

The next step in the implementation is putting together the correct project team with the proper mix of technical knowledge, customer experience and field expertise to deal with the scope of the project in hand. These characteristics must be available from all disciplines such as the procurement, financial, field-erection and design disciplines. Without experience

specifically developed for such modernization projects the chances of all pieces coming together at the proper time is at high risk.

Once these steps are complete, the schedule is in place, the customer is advised, then the monitoring the schedule and dealing with the day-to-day issues becomes routine.

CONCLUSION

It is easy to describe the technical and management requirements needed to take a 25 year operating power plant, and bring it to the standards close to those of present day new apparatus projects. It is quite another feat to execute it.

The Mehrum project is one of the earliest modernization projects which fully gained from the present day possibilities to apply state-of the art technology. Despite knowing that it would be a challenge to maintain the aggressive schedule, and minimal down-time, the project was executed to the planned outage schedule. Upon observance of the results, the cooperation between all sub-contractors and the owner must be recognized key ingredient to the success of these ambitious goals.

The goals were clear. Improve the plant economics to the level possible today, become a cost-competitive contributor to the electrical grid, extend the life of the plant well beyond original design, and serve your community through reduction of environmental impacts. This project successfully realized these goals in the present, and now looks forward to what may be possible in the next century to come.

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