

SCC5-4000F Single Shaft (SST5-5000):

**A single shaft concept for cold cooling water
conditions**

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1 Introduction

Deregulation and liberalization, high loads of renewable energies and high fuel prices change the requirements for new power plants. The customer focus is the optimization of life cycle costs driven by features like high efficiency, high power output and operating flexibility.

Siemens Reference Power Plants are developed with the main emphasis on the above mentioned requirements of modern power markets. Through methods like Quality Function Deployment (QFD) the requirements of power producers are identified and considered in the plant design. A feedback process from projects in construction and commissioning as well as from operating plants ensures a closed lessons learned loop into the Reference Power Plant development.

One result of the QFD workshops is the customer focus on single shaft plants. These plants meet the power producer's need for lowest life cycle cost better than 1x1 multi shafts due to higher availability, higher efficiency and less required space.

In the 400 MW class, Siemens provides two 50 Hz single shaft Reference Power Plants called SCC5-4000F Single Shaft. Both are based on the SGT5-4000F gas turbine (formerly known as V94.3A), the SGen5-2000H hydrogen cooled generator (formerly known as THRI) and a steam turbine coupled through a self shifting and synchronizing (SSS) clutch to the generator. The steam turbine of choice depends on the condenser back pressure, mainly influenced by the cooling condition: The SST5-5000 ,combined HP/IP, double flow LP turbine, (formerly known as KN) shows outstanding performance at low back pressure, the SST5-3000, HP turbine, combined IP/LP turbine, (formerly known as HE) ensures best economic value for higher back pressure.

A second topic addressed by power producers is the need for high operating flexibility. For that reason, all Siemens Reference Plants are designed for both, daily cycling and for base load operation. This flexibility capability was proven through operating units that must cope with different load regimes depending on seasonal electricity demand.

The paper addresses the Reference Power Plant development process, the single shaft design referring to a SCC5-4000F Single Shaft (SST5-5000) and features for high operating flexibility.

2 Market environment

Looking at the European power market as a supplier opens up a quite challenging picture. Liberalization and deregulation, massive support of renewable energy in countries like Germany or Spain and the planned shut down of nuclear power stations in various European countries change the power market fundamentally. Further on, it is still unclear how the political and economical boundary conditions will develop in future: The level of liberalization and deregulation of power markets

in Europe varies from 10% to 100%, gas and oil prices are fluctuating on a high level, the further development of wind energy is a big question mark and the effects of CO₂ certification trading are unsure.

At the same time, there is pressure for replacement of ageing power plants. Huge investments in this uncertain environment are necessary.

Therefore, the requirements for new plants are very challenging to cope with the above mentioned uncertainties. Customers ask for high efficient plants due to high gas prices and CO₂ regulations. Other environmental issues, like chemical and water consumption, are getting more important and have to be taken into account during plant design. Very flexible fossil fired plants must act as back-up for wind power. These plants need compensate the high fluctuation of power output of wind turbines. Due to liberalization and deregulation, the load regime of a power plant over its lifetime is unknown. Therefore, power producers demand for plants that provide a maximum operating flexibility. The ideal design is capable for every load regime from peaking to base load. This market environment also opens up new business opportunities: The use of hourly and seasonal market arbitrage, participation in ancillary energy markets and the capability for peak shaving can increase the economic value of a power plant project.

The task for power plant suppliers is to provide solutions that help customers to overcome these challenges. As an answer Siemens develops high efficient, flexible and environmental friendly Reference Power Plants at lowest life cycle cost and short pay-back times.

3 Reference power plant development

3.1 Investment decision drivers

At the end of the day, an investor's decision on whether or not to realize a specific project will be mainly based on economic facts such as life cycle costs, the project's net present value and the internal rate of return, the cost of electricity and the payback period which in turn depend on project specific boundary requirements. By understanding the most important drivers for optimized customer value, product development is focusing on life-cycle-cost optimization. Efficiency, operating flexibility, reliability and availability, initial invest, operating costs and environmental impact are the main drivers for successful projects (figure 1). The focus on life-cycle-costs has changed the market requirements over the past decade dramatically. Whereas in the past utilities with high technological and financial capacities were the major customer segment, a transition has now been made with emphasis on utilities that are characterized by reduced technology and tight capital resources. This development is driven by liberalization and deregulation of the power markets. The

increased competition has resulted in a new and differently structured market where power generation, transmission and distribution have now been separated from another.

In this market environment, power producers ask for efficiency, high operating flexibility and high availability. At the same time short construction times and low initial investments are expected.

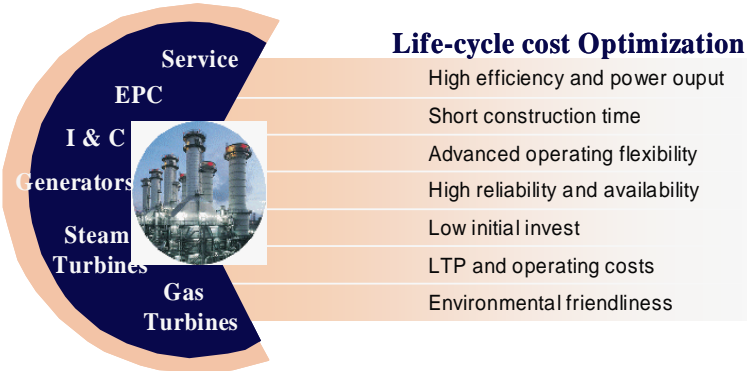


Figure 1: Life-cycle cost optimization

3.2 Reference Power Plant development process

As an answer to these market requirements, Siemens started the Reference Power Plant (RPP) development in the nineties. The modular RPP concept from Siemens enables the design of individually configured power plants applying standardized functional units with logical interfaces to allow flexibility in scope. The development from tailor made plants to standardized plants is shown in figure 2.

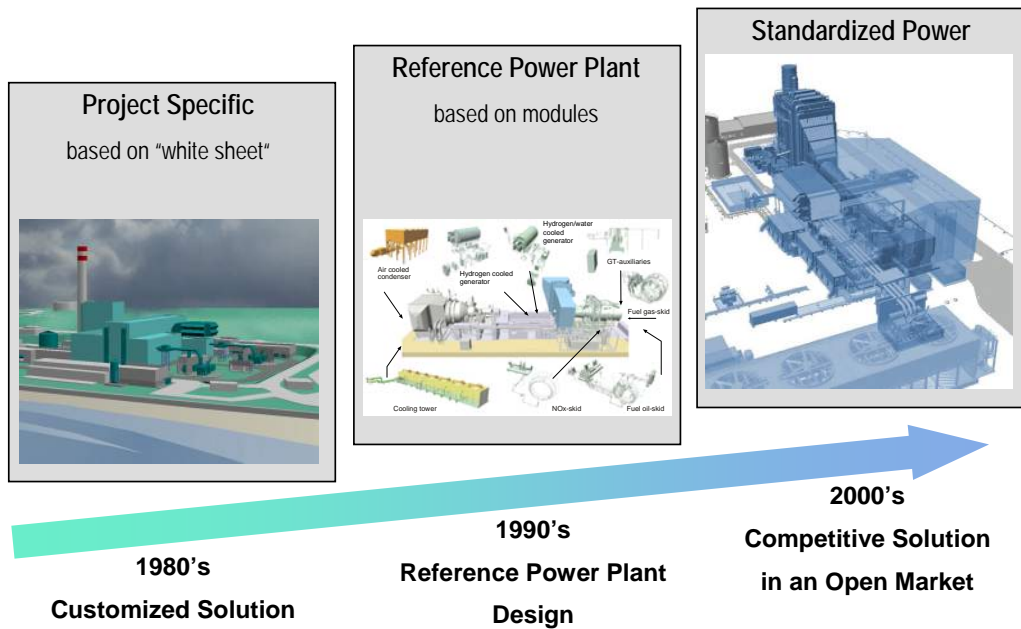


Figure 2: Evolutionary change in design philosophy

Standardization and modularization are the main focus for increasing quality. The objectives of high quality, low costs, and short lead times can only be reached with pre-design and pre-engineered plants. It is a necessity that the RPP is as close as possible to the clients needs without requiring redesign of key plant components. Therefore, the RPP development takes place in close contact to our customers. In Quality Function Deployment (QFD) workshops, different design variants for certain features and requirements are discussed with customers. The needs of the customers are identified and the best solution, which meets the demands regarding technical performance and life cycle costs optimization, is selected. During the development phase customers participate in design reviews and can give their input directly to the RPP development team.

Through close contact to construction, commissioning and operating plants, lessons learned from executed projects flow back to the development. For example, the RPP SCC5-4000F Single Shaft incorporates the experiences of more than 20 units.

Siemens established a Product Development Process to guarantee an outstanding design quality. One important component of this process is a review of the work progress after every design stage like concept design, basic design or detailed design by all faculties along the development, operating and service path. This close monitoring ensures on one hand that the RPP provides an optimal technical concept and on the other hand that it meets the market expectations. Further on, the proc-

ess incorporates state-of-the-art engineering methods like Failure Mode and Effective Analyze (FMEA).

These expenses together with the outstanding Siemens experience as original equipment manufacturer (OEM) and turnkey contractor ensure highest customer value of Siemens Reference Power Plants as described in the next paragraph.

3.3 Benefits of Reference Power Plants

Main focus of the Siemens Reference Power Plants is a core base design which includes the main components as shown in figure 3: gas turbine, steam turbine, generator, heat recovery steam generator and instrumentation and control. For this scope, pre-engineered options like fuel oil as back-up fuel or different cold end variants are available to meet customer wishes and site specific requirements. Only between 20% and 30% of very specific BoP components like water treatment, HV switchyard, or cooling water intake and outfall structures have to be tailor made.

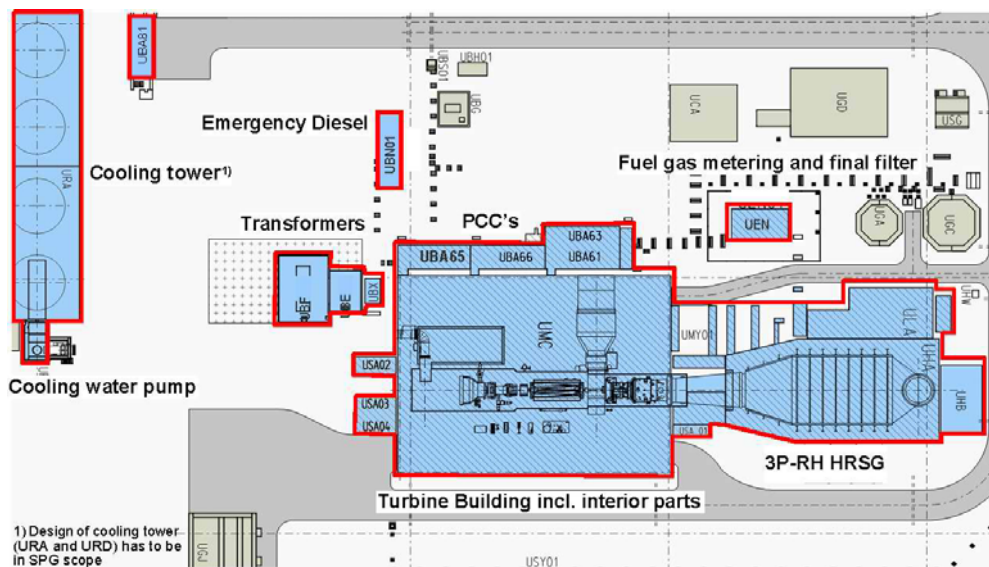


Figure 3: Main Focus of RPP development

This enables Siemens to design a large number of plants with an identical turbine building, while offering the customer the flexibility to meet their site-specific requirements. Major customer benefits of the modularized and standardized RPP concept compared to a tailor made plant are:

- low initial investment and reduced lead time
- higher availability

- increased quality and lower risk

The RPP approach enables Siemens to reduce upfront engineering efforts and expenses in early stages of a project. Replication effects reduce the total project lead time not only in early stages of the project but also during erection and commissioning through learning curve effects. The RPP concept enables the optimization of processes in all fields and provides the required platform for continuous improvement and substantially increasing quality standards. Customer benefits of shorter lead time are: less interest during construction, lower risk at the date of project commission and, if essential, the opportunity to produce power earlier compared to other supplier.

Economics of scale with identical equipment reduce component costs and long term business to business relationships can be implemented, thereby not only reducing costs but also increasing quality of the products.

Altogether, the power producers benefit from lower initial investment at a higher quality level. Modularization and standardization enables the power plant supplier to guarantee a higher availability and reliability of the plant reducing power producer's project risks through proven design. Technical risks, risks associated with subcontractors and schedule risks are reduced.

Additionally, O&M efforts are reduced in various fields. The modularization and standardization approach enables optimized maintenance due to the consideration of O&M requirements already during project planning. Component accessibility is optimized and thus scheduled outages are shortened.

In sum, these benefits by far compensate and exceed the disadvantages through standardization and modularization like reduced layout flexibility, thereby increasing customer value in terms of life cycle cost significantly.

4 Single Shaft Reference Power Plants

4.1 Focus on Single Shaft Power Plants

The RPP development for the European market focuses on single shafts (figure 4). In the QFD workshops, power producers outlined their need for lowest life cycle costs (LCC). The single shaft shows lower LCCs compared to a 1x1 multi shafts due to:

- small footprint due to a compact arrangement
- higher efficiency (one hydrogen cooled generator instead of two air cooled generators)
- higher availability due to less components

There are also advantages of a single shaft over a 2x1 multi shaft, for example higher part load efficiency below 50% load and higher availability. Hence, many customers decide to build two or three single shafts at one site.

Up to now, more than 20 single shaft units with a SGT5-4000F gas turbine are in operation or under construction/commissioning and more than ten further units are in the order backlog.



Figure 4: Single Shaft RPP

Siemens provides two Single Shaft concepts in the 400 MW class for the 50 Hz market. In this paper, the focus is on the SCC5-4000F Single Shaft (SST5-5000), however a short description of the SSC5-4000F Single Shaft (SST5-3000) is given here:

4.2 SCC5-4000F Single Shaft (SST5-3000)

The SCC5-4000F Single Shaft with a steam turbine SST5-3000 is designed with the main focus on the Mediterranean market but depending on e.g. ambient conditions and customer evaluation it is also the preferred variant in other regions. The SST5-3000 consists of a HP turbine and a combined IP/LP turbine with a single flow exhaust. This turbine with an axial exhaust area up to 12.5 m² shows the best economic value in combination with a cooling tower or an air cooled condenser. It is also suitable for one trough cooling with warm cooling water. More than ten SCC5-4000F Single Shaft (SST5-3000) units are in commercial operation all over the world.

4.3 SCC5-4000F Single Shaft (SST5-5000)

4.3.1 Plant Concept

Cold cooling water results in a low condenser back pressure. Therefore a steam turbine with a huge exhaust area is needed. For these locations, Siemens can provide a single shaft RPP with a double flow LP steam turbine. The SCC5-4000F Single Shaft with steam turbine SST5-5000 is optimized for North and Middle Europe. The SST5-5000 consists of a combined HP/IP turbine and a double flow LP turbine with an exhaust area up to $2 \times 12.5 \text{ m}^2$. At the design point of 10°C , the plant achieves with one through cooling an efficiency of about 58.4% net at an output of around 419 MW (figure 5). This high performance saves not only fuel but also reduces CO₂ emissions. Regarding CO₂ trading, this can open up new business opportunities.

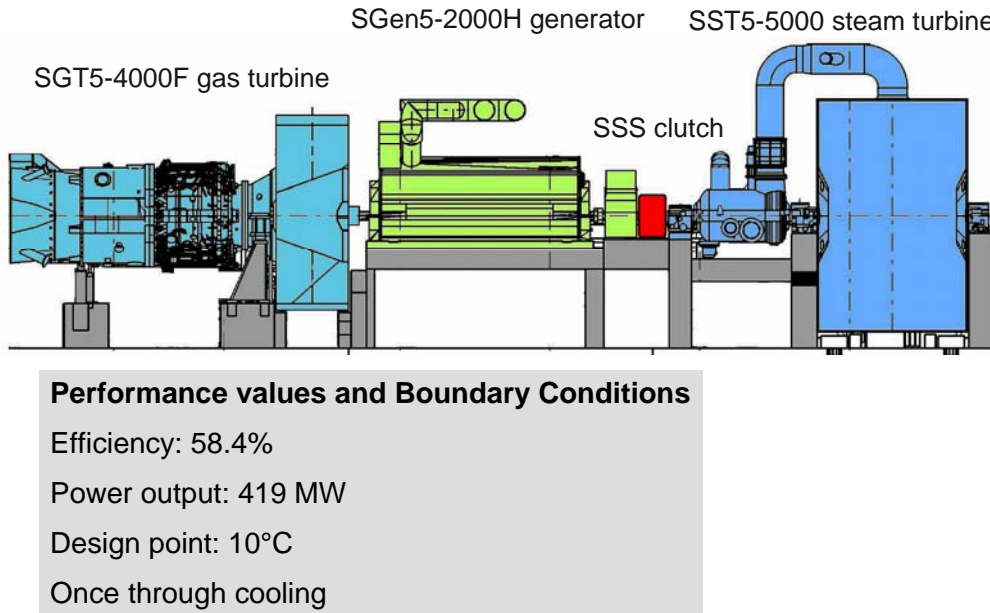


Figure 5: Single Shaft Powertrain

4.3.2 Features of the Single Shaft Concept for Cold Locations

The following main components have been chosen for the SCC5-4000F Single Shaft (SST5-5000):

- Gas Turbine SGT5-4000F (formerly known as V94.3A)
- Generator SGen5-2000H (formerly known as THRI)
- Steam turbine SST5-5000 (formerly known as KN)
- Triple pressure reheat heat recovery steam generator
- Undivided double flow condenser

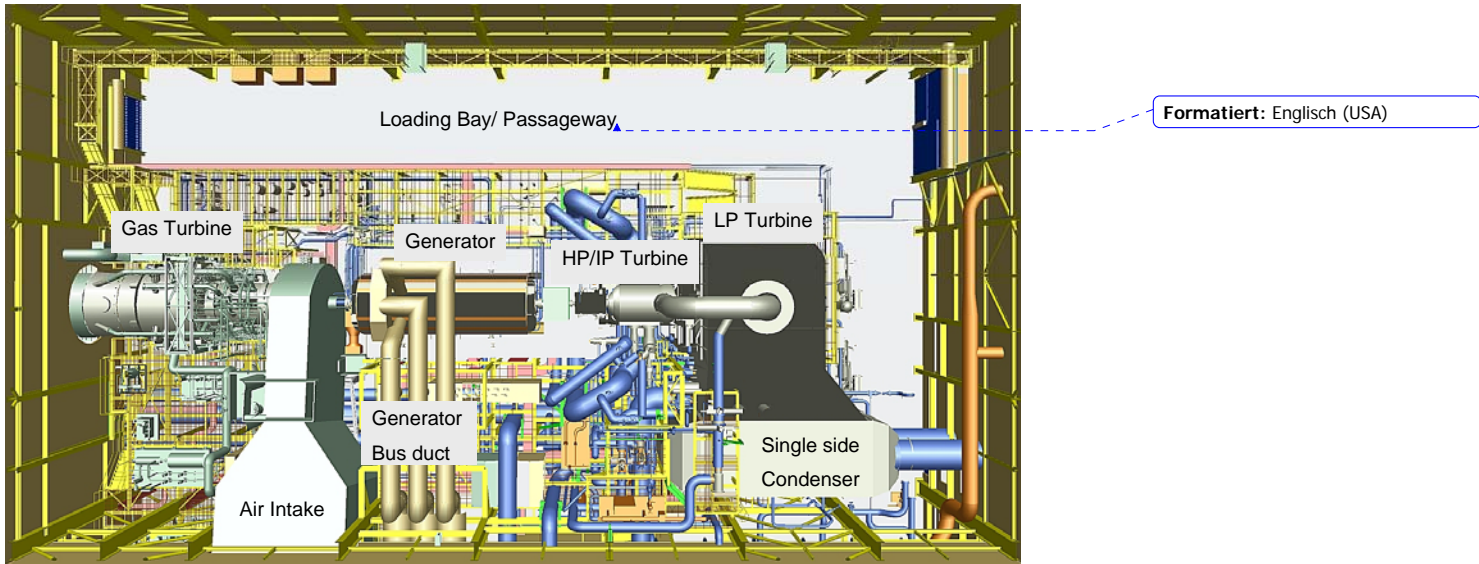


Figure 6: Turbine Building SCC5-4000F Single Shaft

The building concept as shown in figure 6 comprises proven advantages. Key features are:

- Steam turbine connected to the generator through SSS clutch for high availability and operating flexibility
- Generator between gas turbine and steam turbine
- Low level arrangement of power train
- Large loading bay for convenient construction and maintenance
- Full load crane for rapid construction
- Single side exhaust of the steam turbine

The single side exhaust of the steam turbine into a single condenser allows a reduced width of the turbine building as shown in figure 7. This minimizes the footprint of the plant and the overall costs compared to the saddlebag condenser design.

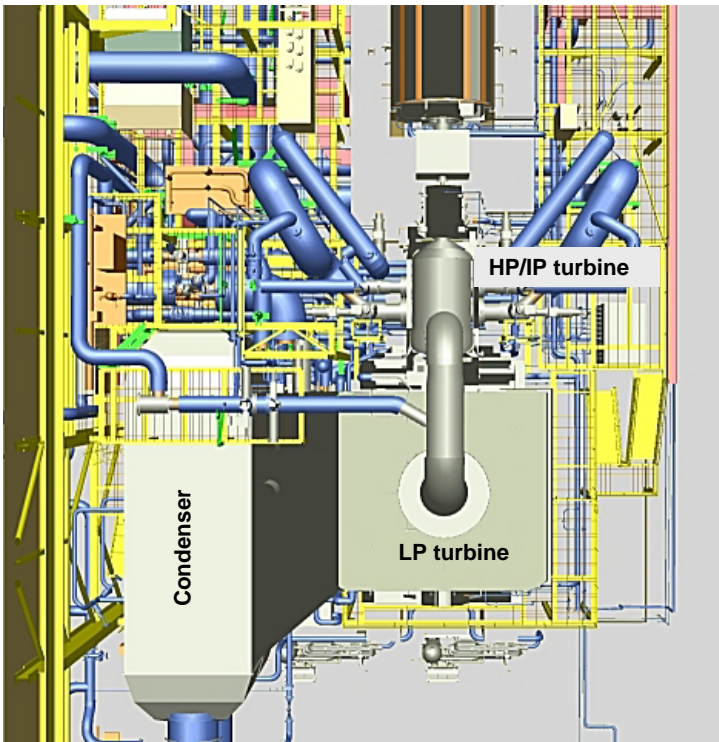


Figure 7: HP/IP LP turbine with single side exhaust

The crane concept for the SCC5-4000F Single Shaft (SST5-5000) considers a full load overhead crane and a 100 t overhead crane for the construction of LP turbine components and the condenser (figure 8). This crane is mounted on an elevated bridge to keep the interfering edge off the full load crane and to provide the necessary height of the crane hook. Therefore, the building height could be reduced. This crane concept is designed for erection and maintenance without any additional temporary lifting devices. It ensures short project lead time and reduced planned outage durations.

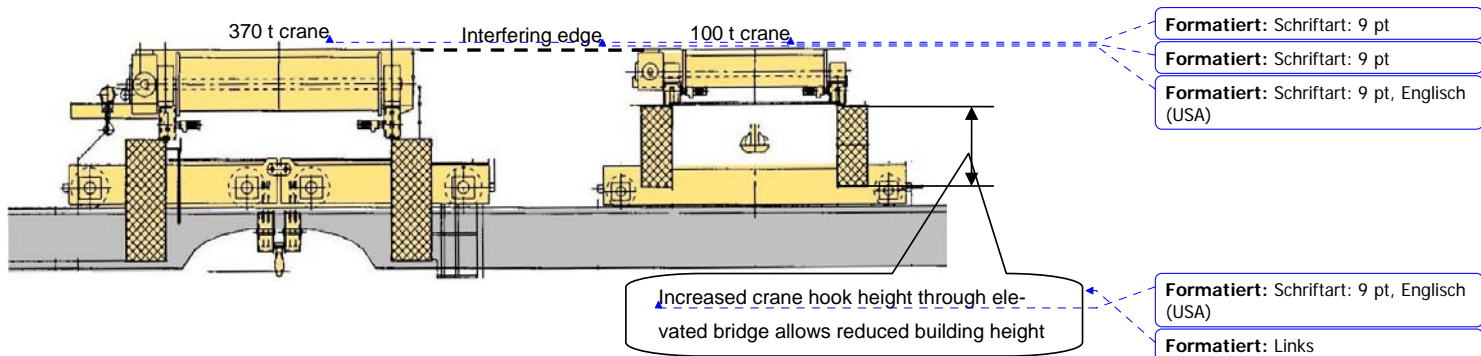


Figure 8: Crane concept: Full load crane (left) and 100 t crane (right)

In addition the plant concept allows steam extraction at good conditions for district heating. Customers often ask for this feature in the target region north and middle Europe.

The concept meets the expectations of the European power market as described at the beginning of this paper. It can play a significant role in the replacement of ageing power plants and nuclear power plants.

In Lubmin near Greifswald, Germany, the first units of SCC5-4000F Single Shaft (SST5-5000) are planned. A letter of intent for three units was signed end of 2003 and the approval planning started middle of 2004.

4.4 Decision criteria

Which of the SCC5-4000F Single Shafts shows the highest economic value, the above explained with a SST5-5000 steam turbine (formerly known as KN) or the plant with a SST5-3000 (formerly known as HE) turbine, has to be defined project specific. In principal, the initial invest for the SST5-3000 is lower, but the performance (power output and efficiency) of the SST5-5000 is higher. Hence, the decision depends on technical facts like condenser back pressure as well as on evaluation criteria for power output and efficiency.

The condenser back pressure is basically influenced by the cooling water temperature and the cooling type. The SST5-3000 steam turbine shows the best value for power plants with condenser back pressures of 50 mbar or more, typical for cooling towers or air cooled condensers. Below 40 mbar, e.g. with once through cooling and cold cooling water, the SST5-3000 is only limited applicable due to too high exhaust steam velocity. In that case, a SST5-5000 with double flow exhaust is the turbine of choice.

In the range in between 40 mbar and 50 mbar, for example for a plant with cooling tower at an ambient temperature of 10°C, the decision depends on the project specific evaluation factors.

5 Operating flexibility

5.1 Challenges in deregulated markets

One result of the QFD workshop was the accentuation of operating flexibility through the power producers. Reasons for that demand can be found in the characteristics of deregulated and liberalized markets. No one knows how fuel and electricity prices will develop and, as a result, in which load regime a power plant can be operated over the plant lifetime.

But these market circumstances also open up new opportunities like utilizing hourly and seasonal market arbitrage, participation in ancillary energy markets or peak shaving. An optimized operating profile increases the economic value of the plant.

In some countries like Germany, Denmark and Spain, the significant and still growing share of wind energy causes new challenges for the operators of fossil power plants. The power output of wind turbines fluctuate heavily and thermal or hydraulic power plants must compensate these fluctuations.

In this market environment, a plant capable for cycling and baseload is a must. The Siemens References Power Plants take this in account. Features like short start-up times, low combined cycle minimum load or full capacity steam bypass stations that allows simple cycle operation enable highest operating flexibility. At the same time, the RPP is capable to operate in baseload without any performance disadvantages.

5.2 Technical features for Cycling

The most important feature for cycling plants is the start-up time. Beside the above mentioned market requirements, fast start-up capabilities shows also operating benefits like lower fuel consumption and higher energy output during start-up which results in a higher *Total Average Efficiency* and supports environmental requirements. Therefore, the Siemens developments for improved cycling capability focus on short start-up times.

An analysis of the start-up process shows that the start-up time is dictated by the maximum allowable stress transients for the steam turbine and the thick-walled parts of the Heat Recovery Steam Generator (HRSG). The restriction of the steam turbine, which requires slow heat soaking, was addressed by changes to the start-up procedure in the control system. Together with an optimization of the warm-up procedure of the steam piping, a significant improvement of the start-up time of the steam turbine was achieved.

The limitation of the HRSG could only be abolished by a change of the design principle for the HP section to the BENSONTM once-through design (figure 8). The BENSON HRSG is developed and patented by Siemens. Since 1999, a BENSON HRSG is successful in operation in Cottam, UK.

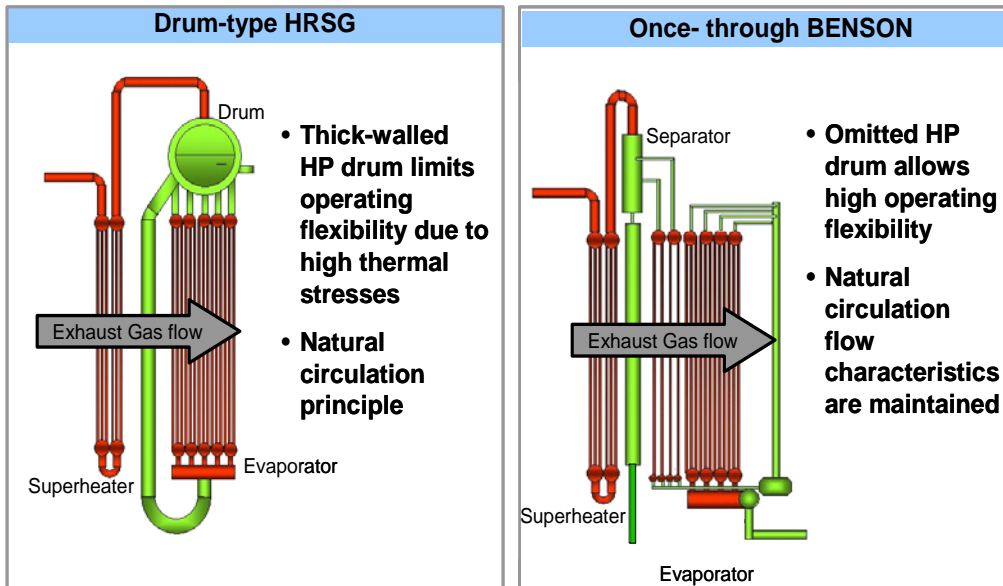


Figure 8: Comparison of drum type and BENSON HRSG

The once through design in the HP part eliminates the thick-walled HP drum and is capable to handle high temperature transients during a fast start-up. The HP drum is replaced by a small separator vessel. The separator performs the function of water/steam separation during start-up and shutdown. At steady state operation, including low loads, the steam flow passes through the separator as part of the interconnecting piping toward the superheater. The steam at the evaporator outlet is slightly superheated; consequently no separation occurs.

The HRSG planned for the Siemens Reference Plant incorporates the BENSON once through design in the HP section of the Boiler. The IP and LP sections remain in conventional drum type design.

Comprising, the Siemens BENSON HRSG retains all the positive features offered by the traditional drum-type HRSG, while providing enhanced cycling capability over drum-type HRSGs.

6 Conclusion

Siemens developed the Reference Power Plant (RPP) approach as an answer to the requirements of a competitive deregulated power market. Input for the RPP development is an extensive analysis of the customer needs through Quality Function Deployment (QFD). In deregulated markets, the customer focus' on life cycle costs (LCCs). The plant concept with lowest LCCs in the 400 MW class is a single shaft plant that shows advantages over a 1x1 multi shaft plant like higher efficiency, higher availability and smaller footprint. Hence, Siemens developed a single shaft incorporating a

SGT5-4000F gas turbine, a SGen5-2000H generator and a steam turbine coupled through a self shifting and synchronizing (SSS) clutch to the generator. As steam turbine, two variants are available: A SST5-3000 with an axial exhaust and a SST5-5000 with a double flow LP turbine. The turbine of choice depends on cooling conditions and economic evaluation of efficiency and power output.

Up to now, more than 20 single shaft units with a SGT5-4000F gas turbine are worldwide in construction/commissioning or operation. The feedback of these projects ensures a continuous improvement. Siemens as an original equipment manufacturer (OEM) has an outstanding knowledge about components and extensive turnkey experience to deliver one-stop power plant solutions. All these facts together result in Reference Power Plants that meet customer expectations in regard to life cycle cost optimization.

The described Reference Power Plant SCC5-4000F Single Shaft (SST5-5000) can play an important role in the replacement of ageing power plants and nuclear power plants in Germany. A letter of intent for three units in Lubmin, Germany is already signed.