Extending the Range of Single-Shaft Combined Cycle Power Plants

Wolfgang Menapace

Edwin Wolt

Martin Wilkening

Siemens AG, Power Generation, Germany

Introduction

Market

Looking at the European Power Market as a supplier opens up a quite confusing picture.

There is the pressure for replacement of ageing power generation facilities which would drive the market to new investments but there is also the unsure situation about CO_2 emissions allocation.

The signed Kyoto protocol and the obligation to reduce CO_2 emissions would favor the execution of efficiency increasing measures whereby this is halted by an unclear situation on gas tax exemption at least in Germany.

The absolute growth of the European market is not very strong but ageing power plants including nuclear plants require refurbishment or even replacement by advanced technologies. Alternative energy sources like wind, hydro and solar power still cannot replace fossil power generation to a large extent. The need for highly efficient fossil power generation remains.

The challenge for the equipment suppliers is to combine highest efficiency with flexibility, low investment costs and short pay-back times.

Proven Concept

So, based on the above, the demand for highly-efficient combined cycle power generation using natural gas has not changed which allows to use well-proven concepts like the Siemens Single-Shaft combined cycle concept. There are some arguments for the single-shaft concept over the multi-shaft arrangement like small footprint or easy modular structure of multi-unit arrangements. An important argument in a deregulated market may be the possibility to sell single blocks to different investors or to build up a power plant location step by step. Additionally the smaller number of main components and a clearer process design over a multi-shaft even improves reliability and availability.

Figure 1 *Proven Concept – CC 1S.V94.3A Combined Cycle Power Plant*

Based on these thoughts the intention of the ongoing development efforts for this product is to continuously improve the product and increase efficiency and customer value as much as possible today.

Single-shaft arrangement for cooler climate locations

It is in the nature of condensing steam turbines that they are designed for certain back pressure levels which can range from 25 mbar for fresh-water cooling up to over 100 mbar for air-cooled condenser applications. Consequently the exhaust area varies from 4m² up to over 12m² for single exhaust machines. Today's available steel blade design of up to 12,5m²

sometimes is not sufficient for cold locations and growing gas turbine heat input at the same time.
The paper will show how it finally was possible to keep the strong points of the single-shaft design and add the advantages of increased exhaust area.

Benson HRSG
The major challenge to increase the cycling capabilities of a highly efficient combined cycle power plant basically comes down to the question of how thermal stress in the HRSG and the steam turbine can be controlled.
An operator who is more flexible to ramp up his plant according to a request from the load dispatcher will always be more competitive and make the race for the best power supply price or to be dispatched at all.

Standardization

In the race for highest efficiency and maximum flexibility though there may be product quality and thus reliability and availability at risk. Therefore the task for the developer is to always consider reliability factors while making changes to the design.
But there is one major chance to drive quality: standardization and modularization.

Because of the clear and integrated technical structure of a single-shaft plant the supplier has the complete design control over the power train including the main components.

This gives a chance to standardize the layout and design of the core of the plant and thus subsequently increase purchasing volume and the opportunity to prove the reliability of the applied equipment. This is the reason why we believe in the push for quality by standardization. The result will be a standardized and extended Power Island scope, called Power Block, of our existing single-shaft combined-cycle power plant design.

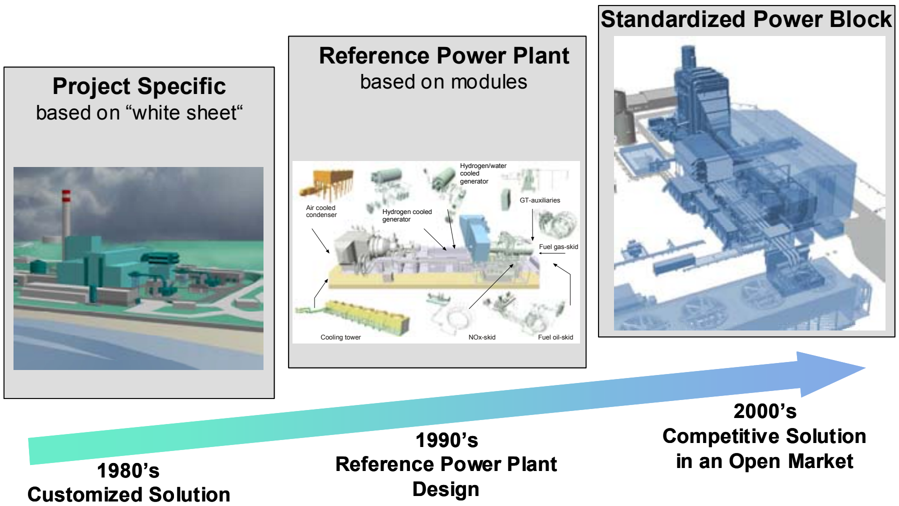

Figure 2 *Evolutionary change in design philosophy*

Of all the results the most decisive one was that limited climatic differences of sites lead to only minor changes in nominal plant heat rate and output.

The solution appears to be: engineer a plant with optimized processes and components for a range of climatic conditions so that most of the layout and equipment can cover a series of potential projects, subsequently realizing a high repeat rate.

With this approach a larger number of plants can be designed with identical core called Power Block, while offering our customers the flexibility to match their site-specific requirements.

Major benefits are:

- cost saving
- project lead time reduction
- lower project risk

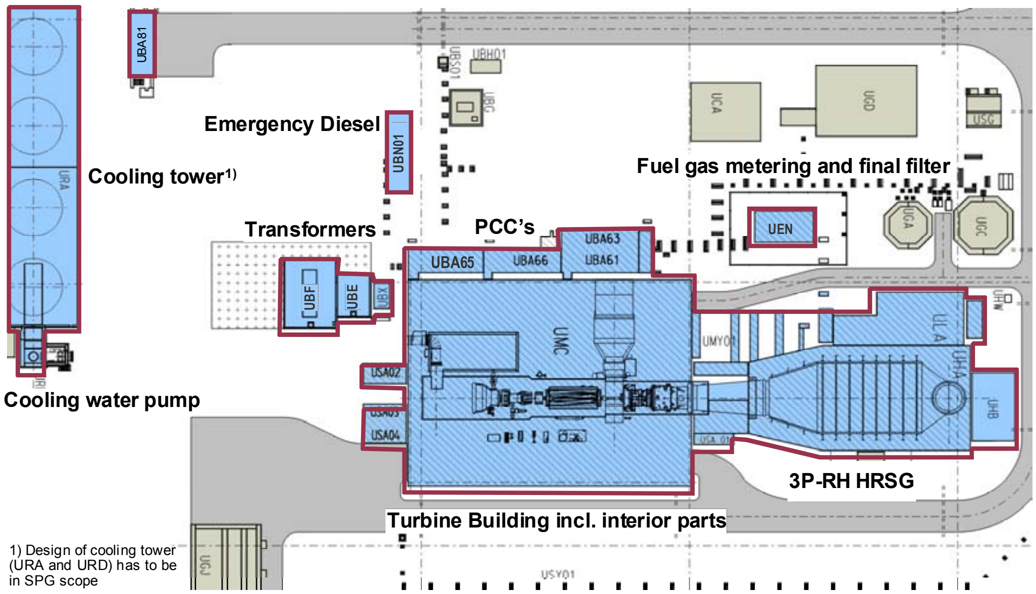

Figure 3 *The standardized Power Block*

Cost Savings

The most significant savings can be generated through economics of scale for identical equipment. Multiple purchase agreements define scope, design, terms and conditions and result in a learning curve for price and delivery time.

Savings in terms of engineering within the standardized plant core are achieved if the engineering for the first project is transferred as much as possible to subsequent projects. The installation costs will also be reduced as a result of repetition effects, improved bills of quantity (BOQs) and fewer non-conformances.

Project Lead Time Reduction

The time schedule for a power plant project implementation can in many cases be shortened. Especially if a plant is provided by a turnkey supplier, all steps can be perfectly coordinated.

Less time is needed for the design and purchasing of all key components because they are already engineered and only need to be called up. Time savings also result from reduced engineering efforts plus plant construction and commissioning can be speeded up.

Lower Project Risk

The project risk, consisting basically of non-conformances, delays, and non-availability, is significantly reduced through the utilization of existing, proven design and identical equipment. The entire course of the project will also be much more stable because possible uncertainties and unforeseen incidents will be essentially precluded by utilizing experiences gained.

Servicing the plant during future operation will be easier and the risk of failure will be smaller. The availability of spare parts after an unscheduled outage will be much better.

Customer Benefits at a Glance

Our customers benefit to an even greater extent from the advantages offered by field-proven, identical design and equipment:

- Reliable planning and expedited licensing and approval of the project
- Low project risks through standardized, field-proven layout and components
- On line 2 or 4 months earlier
- Higher plant performance through optimally matched processes and components from a single source
- Reliable plant operation thanks to field-proven, identical components
- Less expenditure for spare parts when operating identical power plants
- Higher flexibility in deployment of service and operating personnel
- Greater and more easy-to-realize improvement potentials identified in plant operation.

Single-shaft for cooler climate locations

As described in the previous chapter, standardization of the single-shaft reference power plant with the HE steam turbine has reached a mature state. Further standardization potential is expected for the single-shaft concept with the KN steam turbine (Combined HP/IP turbine, double flow LP turbine).

The CC 1S.V94.3A with the HE steam turbine is restricted in its operational range at cold climate locations due to the limited ST exhaust area of 12,5 m² (single flow exhaust). Therefore we developed our single-shaft reference power plant one step further for use in cooler climate zones (Figure 4). The possible size range of the exhaust annulus is then extended to 25m² allowing a considerable increase in efficiency which also means direct CO_2 reduction. As an example the application of the new KN-single shaft in change for the HE-single shaft can save up to 20.000 tons of CO_2 per year where cooling water with 10°C is available. In a world with direct CO_2 penalties this would pay back directly to the owner of the plant.

Figure 4 *Target region for cold-conditions Single-Shaft*

The defining feature of this plant is the KN steam turbine comprising a double-flow low-pressure turbine with a single side exhaust system. The following main components have been chosen for this plant concept:

- V94.3A Gas turbine
- Combined HP/IP steam turbine (K30-16, N30-2x12,5m²)
- Hydrogen cooled generator (THRI 50-20)
- Triple-pressure reheat heat recovery steam generator
- Undivided double flow condenser

The turbine building layout is shown in figure 5.

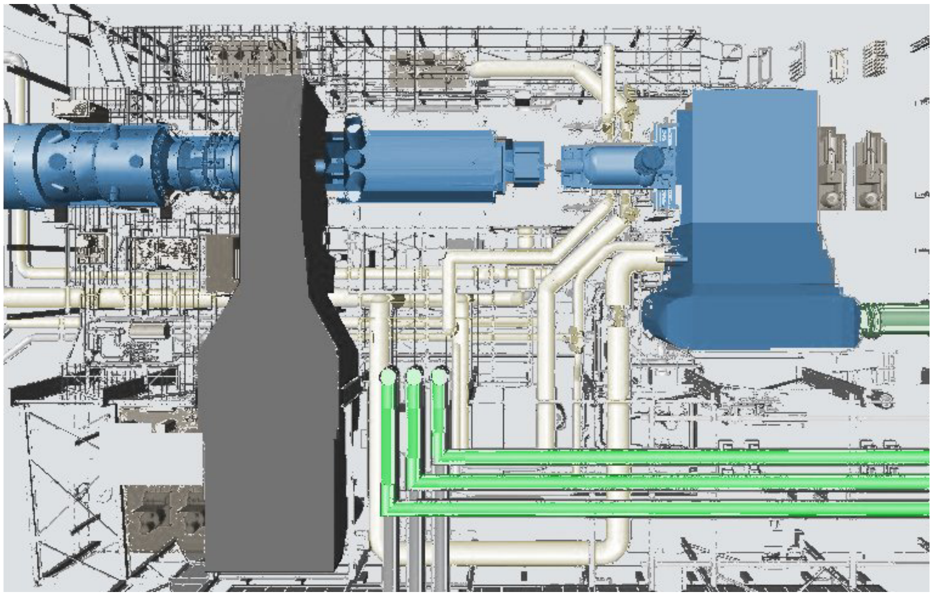

Figure 5 *Power train of cold-condition Single-Shaft*

The building concept comprises the same proven advantages as for the single-shaft with HE turbine:

- Steam turbine connected to the generator through SSS clutch for high availability and operating flexibility
- Generator between CT and ST (see figure 5)
- Low level arrangement of power train
- Large loading bay for convenient construction and maintenance
- Full load crane for rapid construction

The single side exhaust of the steam turbine into a single condenser allows to reduce the width of the turbine building to reduce overall costs (see figure 6) compared to the saddlebag condenser design.

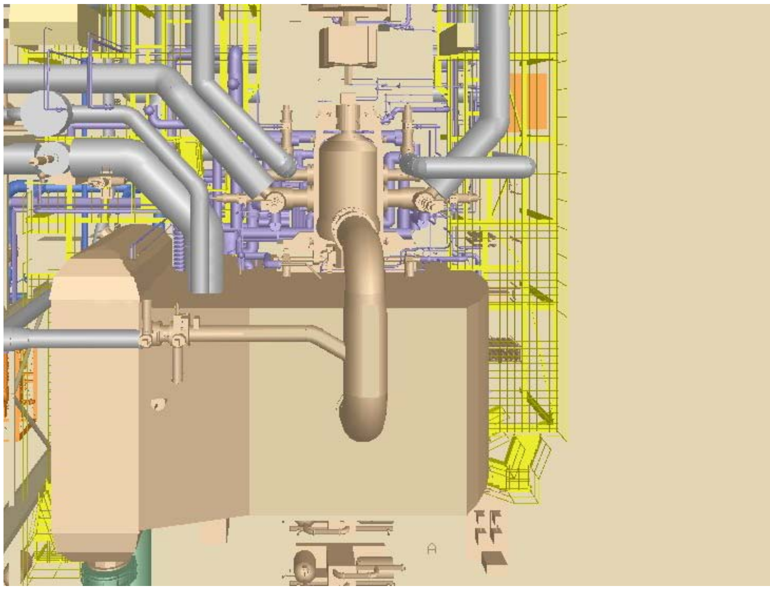

Figure 6 Single-side condenser of cold-condition Single-Shaft

This plant takes advantage of the low cooling temperatures in Central Europe (average air/cooling water temperature about 10°C) to achieve an efficiency of about 57.9 percent net at an output of around 417 megawatts (10°C design point). The plant concept is optimized for once through cooling by implementation of the large double LP turbine with a last row blade length of 1145 mm (2x12,5 m²).

The crane concept for the 1S.V94.3A KN considers a full load EOT crane and a 50 t EOT crane mainly used for construction of the LP turbine components (figure 7). This crane is mounted on an elevated bridge and comprises the following advantages:

- Low turbine building height due to elevated 50 t crane hook height
- Higher flexibility during erection and maintenance
- No temporary lifting devices are needed for installation or maintenance activities
- Enables short project lead time and reduced planned outage durations

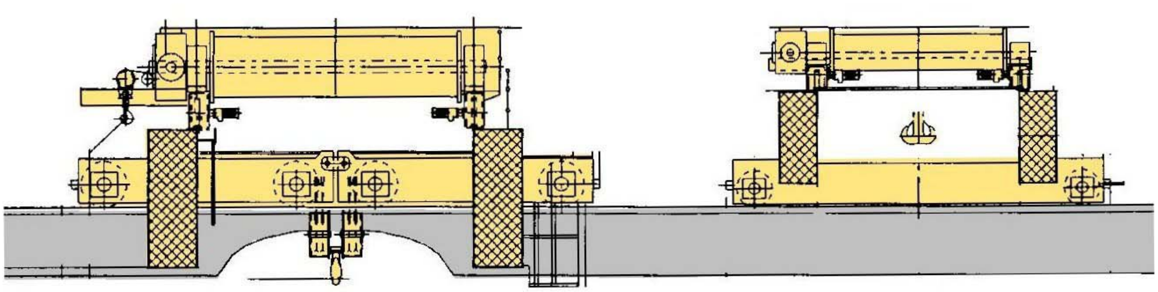

Figure 7 New crane concept

In addition the plant concept allows steam extraction from the steam turbine at optimal conditions for district heating. Since the target region is Central Europe this is a required feature for this region.

Through the benefits of the large LP turbine optimized for once through cooling the plant concept contributes significantly to CO_2 reduction in the power market. The turbine offers also further upgrade potential for future gas turbine developments.

We see a very good standardization potential since the chosen design conditions of 10°C ambient temperature and 10°C cooling water temperature match real conditions at many locations in Central Europe. This allows to keep most components of the power plant constant independently of different sites. Since it is expected that a large number of power plants in Germany have to be replaced within the next 10 years this plant concept offers an excellent alternative to other power plant configurations.

Benson Once -Through Steam Generator (OTSG)

The analysis of the start-up process revealed 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 restrictions of the steam turbine, which requires slow heat soaking, was addressed by changes to the start-up procedure in the control system.
The limitation of the HRSG could only be solved by a radical change of the principle which was luckily available with the Benson once-through design.
We successfully applied the Benson evaporator principle in a 390 MW combined-cycle application at Cottam Development Center (United Kingdom). This state-of-the-art single-shaft facility has been in commercial operation since 1999. During this period the patented horizontal Benson OTSG has shown its direct applicability for fast-start up and cycling operation because of better thermal flexibility. In addition it allows highest growth potential regarding steam conditions with live steam pressures over 150 bar utilizing future gas turbine exhaust energy.

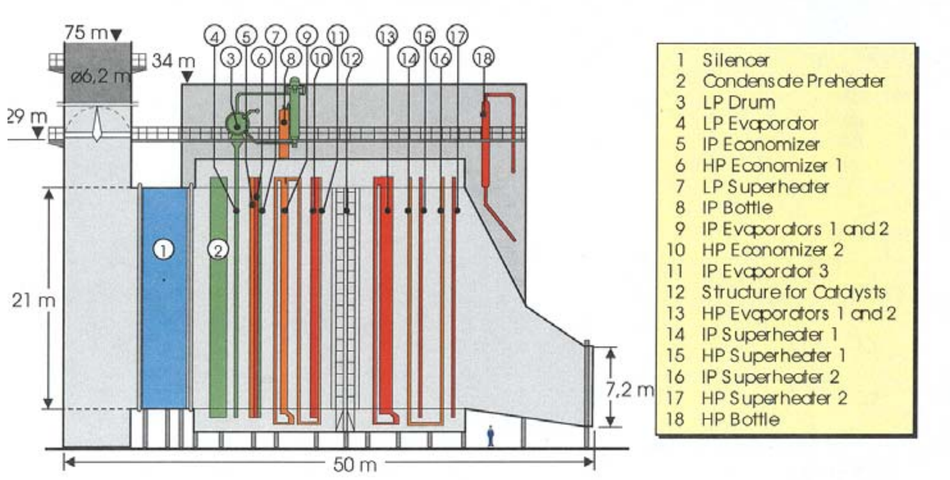

Figure 8 *Benson-OTSG at Cottam Development Center (triple-pressure reheat steam cycle)*

The Benson-OTSG is capable of handling high temperature transients during a fast start-up due to eliminated thick-walled steam drums. The Benson-OTSG eliminates the restrictions of the water/steam drums by replacing the drum with 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.

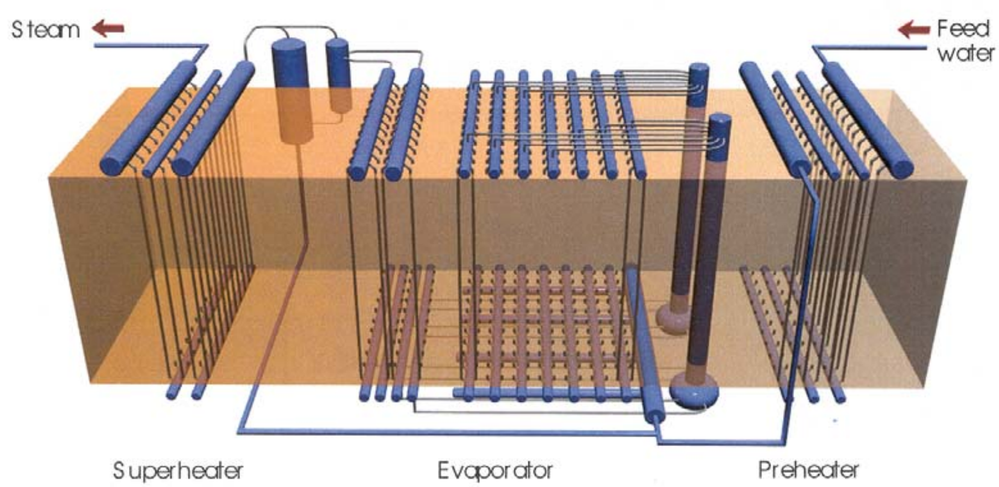

Figure 9 *Once-Through Steam Generator Section*

In contrast with a drum-type HRSG, the Benson OTSG is able to control the main steam temperature by modulating the feedwater mass flow. This enables the system to compensate the effects of changing ambient conditions or GT loads within a certain range without placing the steam attemperators in operation. Attemperators are incorporated as interstage, as well as final-stage de-superheater for the high pressure and reheat steam systems. This arrangement ensures compliance with the steam temperature limits, dictated by the steam turbine during plant start-up.

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

Summary

As a successful result of the enlarged portfolio for single-shaft power plants the market gives positive feedback. The first single-shaft plant with a double flow LP turbine was installed in the Donaustadt plant near Vienna. This plant delivers also a high amount of steam for district heating.

The first new “cold” single-shaft design is being used as the basis for the Siemens PG bid for the Lubmin turnkey project in Germany, where it has already received the customer's approval.

Also the standardization efforts resulted if several orders for single-shaft plants based on the standard Power Block.