Taking Advantage of Market Opportunities through
Siemens Reference Power Plants
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1. Introduction
In a market where requirements and the operational environment for plant are changing rather rapidly compared to former years, flexibility is one key driver for business success. Besides the requirement for high performance and high availability to achieve low life cycle cost, flexibility in the plant operations and maintenance are strong drivers.
This paper presents two Siemens PG developments for increased flexibility to support our customers in successful competition in the power market.
Starting with a short description of the market requirements driving flexibility demand and a rough sketch of the Siemens Reference Power Plant philosophy two exemplary Siemens solutions for flexibility needs are presented.
The first solution is shown on a new addition to the RPP portfolio. The SCC5-3000E 1S is a Single Shaft plant in the 300MW range, rounding the Siemens heavy duty power plant portfolio at the lower output end. This plant features unique flexibility regarding maintenance and shows how the requirement for higher power demand in certain times can be balanced with the requirement for increased maintenance intervals.
The second solution is increasing the operational flexibility of combined cycle plants by enabling faster start up of the plant. Such the power market demands can be followed more rapidly and economically. Additionally the customer gains access to new opportunities in the ancillary market.

2. Market environment
We strengthen our customers - to keep them competitive. This is one of the Siemens principles. For the RPP development this translates into focusing on the customer perspective for development decisions. Therefore the market requirements and the respective influence factors from a customer perspective are the starting point for the economical evaluation. This is done by selecting a geographical target market for a RPP and deriving the market requirements and influencing factors for this market from a plant operators point of view. With the specific influence factors the component and plant layout decisions are verified for their customer benefit. Only options that have a positive customer benefit will be realized and build the backbone of the RPP.
In a market study two third of the EU power retail markets are shown to be opened for competition (Lit 1). However in some of those markets large power generation companies rule the competition. In those markets that are open and where a certain diversity of generating capacity and accessibility to the grid is given, e.g. in liquid markets, the requirements on plants are changing to
include flexibility additionally to the 'usual' requirements on performance and availability to consistently achieve economical operation.

Flexibility in this context can be described by the capability to follow the market on the supply side (fuel price, fuel availability) and the demand side (hourly, daily or seasonal power revenue, ancillary services). The changing parameters on both, supply and demand side, bear risks for plant owners. Whereas combined cycle power plants in the 90th were planned as base load plants, today's fuel price volatility and the liberalization drive the duty cycle in many cases into the intermediate or cycling operational regime. A plant solely designed for base duty may not be able to follow those changes in market environment efficiently. Additionally the liberalization provides market opportunities like ancillary products that can add to the revenue stream if the services can be supported by a flexible plant.

Having a large combined cycle power plant online faster does increase the flexibility to respond to the requirements and such increases competitiveness for the operator. Description of the improvements in plant start up time for a large heavy duty Siemens combined cycle power plant is one of the flexibility features described in the paper.

Flexibility can play an important role not only on the operations side. Flexibility is as well a valuable asset in the field of maintenance. As for the operational flexibility, maintenance flexibility can come in several different facets. One of those is the capability to influence the maintenance intervals depending not only by the duty cycle, but by the power output of the plant. Such the operator can influence the time till the next major outage to shift it where possible to a time of low revenue potential by changing the plant output. This feature is described by the example of an addition to our existing reference plant portfolio, the SCC5-3000E 1S.

3. Extension of RPP portfolio

Since the 1990th Siemens develops the Reference Power Plants (RPP) as a project neutral development of combined cycle or steam power plants. The plant is kept flexible by using a modular design approach with pre-designed modules covering different applications. Thus the plant can easily be adapted to customer or site specific requirements by selection of the respective modules for the most common applications. Upgrades of components or in the BOP area are introduced into the plant design on a continuous base as well as inclusion of lessons learned from executed projects. This feedback loop assures highest design quality.

Optimization is done on the life cycle base with the focus on overall plant design. This assures highest customer value by considering the whole plant and the whole life cycle (planning, permitting, erection, commissioning, operation and maintenance) in the layout phase.

The RPPs are developed for defined climatic regions mirroring the major markets. However a transfer to other climatic regions can easily be done based on the modular approach. Impact on
plant performance through the reference plant approach vs. a specific layout are small and are far outweighed by the reduced risk and delivery time.

The current Siemens heavy duty combined cycle RPP portfolio ranges in the 50Hz market from about 100MW to 800MW per unit. Using multi unit configuration multiples of those outputs can be achieved according to the customer requirements.

The SCC5-3000E 1S is an addition to the Siemens portfolio in the lower power output range with a block size of ~300MW. It targets the need for high availability and reliability with good fuel efficiency and long service intervals for a competitive price. As a special feature it can provide flexible service intervals for different plant outputs.

3.1. New RPP SCC5-3000E 1S

3.1.1. Gas Turbine

By identifying the gap in power output between a 100MW unit and the 400MW unit the market potential for a ~300MW unit size is tapped with the selection of the SGT5-3000E as the core for the plant. Different plant concepts and main components were investigated for the LCC impact and the most economical solution selected.

The gas turbine as the plant core is a derated version of the well proven SGT5-4000F. The whole design of the SGT5-3000E is based on a common parts approach with the SGT5-4000F. To utilize most of the operational experience and to gain additionally the benefit of larger quantities in parts purchase and logistics, the SGT5-3000E has ~95% identical parts with the SGT5-4000F.

To reduce the gas turbine in power, the compressor was adjusted to provide a lower mass flow. The compressor vanes were re-staggered and adjusted. The first stage blade row was slightly modified by maintained stagger angle to increase surge margin especially for high ambient temperatures. To improve turbine efficiency, the row one vane was slightly re-staggered. The casting stock tolerances of this vane are such that the restaggering is done by machining of the same casting as for the SGT5-4000F.
As the turbine inlet temperature was reduced with all other hot gas path components unchanged, the service intervals between major overhauls could be extended to 33,000 EOH (33MAC) for the higher power output and 41,000 EOH (41MAC) for the lower power output setting. This lead to an increase in availability and a reduction in service cost. Much attention was given to cooling air savings for further NOx emission reduction (Lit 2).

![41MAC: 41,000 EOH Concept (with standard firing temperature)](image)

![33MAC: 33,000 EOH Concept (with elevated firing temperature)](image)

*) **MAC** = **MA**intenance **Concept**

The capability of the gas turbine to run in different service intervals with different power ratings is proven by the vast experience with the hot gas components from the established SGT5-4000F fleet with higher firing temperatures. The SGT5-4000F has now clocked more than 2 million EOH with the leading unit having more than 70,000EOH to data (Jan. 2006).

### 3.1.2. Steam Turbine

The steam turbine selected for this application is the SST5-900RH, an addition to the Siemens portfolio since the acquisition of the industrial turbine portfolio from Alstom. The turbine is of two casing design with a high pressure and a combined intermediate / low pressure turbine. The application of this turbine ranges from industrial to heavy duty with more than 100 units sold. The HP part is designed as a barrel type and operated at elevated rotational speed to give a much more compact and efficient design. The HP turbine is coupled through a gear to the main shaft. The gear transmits only the power of the HP turbine (<30MW) to keep in a standard gear design envelope. This shaft train setup has already been realized in a combined cycle plant.

The IP/LP is a single casing turbine with a modular setup to accommodate different exhaust and extraction variants. The selected configuration is compact and efficient with an axial exhaust to the directly coupled condenser.
3.1.3. Generator
A hydrogen cooled Generator has been selected for this plant configuration. The increased efficiency of the hydrogen cooling compared to an air cooled generator makes up for the slightly higher component cost. Additionally low power factors as currently demanded in some markets are supported with a single setup. As standard for our RPPs, the component selection is based on the life cycle cost evaluation and NPV evaluation. With more than 700GW of installed generator capacity, Siemens is one of the most experienced suppliers worldwide.

3.1.4. Plant Design
With the target of about 300MW unit size, the individual component selection and the different plant configurations (Multi- or Single Shaft, 2 or 3 pressure, reheat or non reheat) have been evaluated. The configuration with the highest evaluated NPV proved to be the Single Shaft configuration with a three pressure reheat bottoming cycle. The gas turbine is directly coupled to the generator. The steam turbine is coupled via an SSS clutch to enable unrestricted gas turbine start up. For a compact plant layout and highest efficiency, the HP steam turbine power is coupled via the gear between SSS clutch and IP/LP steam turbine. The general plant layout is taken from our proven standardised Single Shaft plant, the SCC5-4000F 1S. Again for high reliability and availability as well as risk reduction, layout, components and design and service philosophies are transferred where applicable and economic.

Figure 1 SCC5-3000E shaft train layout

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3.1.5. **Flexible maintenance interval**

The stresses for the hot gas path components depend amongst other on the operating temperature they are subjected to. By decreasing the firing temperature compared to the SGT5-4000F, the SGT5-3000E service on the hot gas path components can be extended. As the components with the shortest refurbishment or life interval governs the achievable service interval, significant design effort was made to achieve a common usage rate of the components for the different performance ratings. With the appropriate adjustment of the firing temperature the two maintenance concepts with 33MAC and 41MAC are achieved. The performance ratings of the two concepts are shown in Table 1.

<table>
<thead>
<tr>
<th>CC rating SCC5-3000E 1S</th>
<th>33MAC</th>
<th>41MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Power Output, MW</td>
<td>305</td>
<td>289</td>
</tr>
<tr>
<td>Net Heat Rate, kJ/kWh</td>
<td>6328</td>
<td>6368</td>
</tr>
<tr>
<td>Net Efficiency, %</td>
<td>56.9</td>
<td>56.5</td>
</tr>
<tr>
<td>NOx Emissions, ppmvd @ 15% O2</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 1 Combined cycle performance rating for SCC5-3000E 1S at ISO conditions**

Up to here, the two concept stand separately for two different business models. Either operating the plant with high performance and service intervals extended to compared to a F-class unit, or with even longer service intervals and derated power output. However the prediction which would be the most favourable operating regime long term is a difficult one in nowadays changing market environment.
The SCC5-3000E 1S plant offers a new solution. The two service concepts can be integrated into a single more flexible one. Depending on the market situation, the plant may be operated with a lower output but longer service intervals is this is the most economical solution. With a change in demand and higher achievable electricity revenues, the plant can run up in power to participate in this beneficial market. This additional performance will come at the cost of slightly higher life consumption. Once the market is back to the former prices, the plant is reduced in output and returns to the extended service interval setting.

This gives the plant operator or dispatcher a unique opportunity to react on the market situation by changing the service intervals. The feature can be used in the other direction, e.g. to shift the next outage to the most economical time by operating at a higher or lower power setting.

The changes in regime are governed by the selected turbine inlet temperature. Starting from the base of the 41MAC concept, the EOH counter runs faster for the time additional power above the base setting is called. With the return to base setting, the EOH counter returns to the usual count.

![Figure 3 Exemplary curve of power and EOH counter for flexible maintenance concept](image)

Above mentioned flexible maintenance concept has already been sold into the market place for customers benefit on our proven SCC5-2000E plant. The plant is currently build and is scheduled for commercial operation in xxx

### 4. Fast start up

#### 4.1. Idea

A change in fuel price can shift a power plant to higher or lower merit order in the dispatch rank. With the current high in the gas prices, a combined cycle plant planned for base load can be
required to operate in intermediate or daily cycling mode to be economical. The changing market
environments can additionally open up other market opportunities like ancillary markets and short
term trading. Especially for those operational regimes a fast start up capability enables a plant in
standby to participate in a spinning reserve market or in an hour ahead trading scheme.

4.2. Plant requirements
The concept is based on the proven Siemens Reference Power Plant design and requires only
one real change in plant equipment and modification in plant master control.

According to the market requirements most Siemens RPPs were designed as base load plants.
With the low number of starts, the requirements on start up time for a hot start were low,
100 minutes were acceptable for a 400MW single shaft plant. The changes in market however
change the importance of plant features. The business benefit from a faster start up is significantly
different for a cycling plant that starts five times a week (see paper on commercial xxx).

The real hardware change necessary to allow a faster start up is the implementation of a
BENSON® evaporator in the HRSG high pressure section together with a condensate polishing
plant (CPP) (Lit 3). The introduction of a BENSON HP stage eliminates thick wall components like
the HP drum and allows higher temperature and pressure gradients during start-up compared with
a drum type HRSG. This design enables an unrestricted gas turbine start for a wide range of gas
turbine ramp gradients including advances currently under development. The implementation of
the CPP is necessary to for the water chemistry of a BENSON HRSG and provides the high water
quality for all pressure stages. Additionally, the CPP reduces wait time for steam chemistry
considerably. With those changes an unlimited ramp up of the gas turbine is feasible.

Siemens as the OEM turnkey provider has the experience and knowledge to optimize not only
individual components but the whole plant. For the complete picture of start up time optimization
not only gas turbine and HRSG needs to be involved but an holistic approach was taken involving
all faculties in plant design. With all parties working together further potential was identified by a
revised unit start up procedure for hot starts (about 8hrs. downtime). The interaction of gas
turbine, steam turbine and BoP was optimized. The result is the so called parallel start up
procedure where the gas turbine is started and ramped up with its maximum allowable gradient.
The exhaust gas is lead through the HRSG and the first steam is directly used for steam turbine
roll off. Due to the condensate polishing plant there is no wait time for steam purity.

4.3. Test / commercialization
Such a concept requires an advanced control concept for the water-steam cycle and the steam
turbine. The first field test was run with manual control to prove the concept. Now the automated
control concept was tested for the first time in a field unit with a start up time from standby to full
load of less than 40 minutes for a single shaft 400MW plant.
The new concept is not only applicable for new plants but also available as upgrade package for plants in operation. After analyzing and assessing the existing plant design and equipment, Siemens can define fast start-up features which could be implemented without any disadvantages regarding plant performance and lifetime.

Some fast start-up features are already implemented in plants in Spain and Portugal and proven during commissioning and commercial operation.

5. Summary
The paper shows two examples of Siemens Reference Power Plant solutions for the increasing requirements for flexibility in our current changing markets.

The market environment is changing driven by liberalization and volatile changes in fuel cost and electricity revenues. Additionally the changing markets provide opportunities for new power products. In reaction to the changing market needs, Siemens focuses on further improvement of flexibility of the proven RPP plants. Two of those improvements are described in the paper:

Fast start up for cycling plants
A new RPP with extended and flexible maintenance intervals
Both developments extend the current market expectations.
The start up of a large combined cycle plant in less than 40 minutes is possible in a collaborative effort of all parties involved in plant design and operation and the experience base of Siemens as a turnkey power plant provider.

Significantly longer service intervals for base operation of a high efficiency plant with the capability to increase performance by shortening the intervals have the advantage to reduce operating cost while providing extra power when the market situation is advantageous. This capability can be used as well for shifting of the maintenance outage to a more preferable low revenue time.

6. Literature

Lit 2 50-Hz Heavy Duty Gas Turbines – Experience and Evolution, Hans Maghon, Bernd Stöcker, Dietmar Granser; Power Gen Asia 2005
Lit 3 Fast Cycling Capability for New Plants and Upgrade Opportunities, H. Emberger, E. Schmid, E. Gobrecht; Power Gen Asia 2005