The SGT-8000H Series and its advantages for the European Power Market

Autor: Armin Städtler, 8000H Product Manager
Co-Author: Dr. Kais Sfar, Energy Solutions Product Line Management
Abstract

The future of the European Power Market with regards to adding new generation is more volatile than ever. Still there is the need for large generation and the SGT5-8000H and related power plants will play a significant role for such applications.

Backed up by 3 years of commercial operation and proven operational track record combined with high efficiency and operational flexibility, the SGT-8000H fleet is growing fast and has become a main pillar of the Siemens Fossil Energy Portfolio. Consequentially the focus of the 8000H program has changed. In the early years focus was on design of the engine, later-on switching to validation of the 50Hz engine, then moving on the design and validation of the 60Hz unit. Nowadays with many projects won the primary focus of Siemens is of course in the execution of the projects in order to deliver what was promised – in performance but also in quality and time. The paper will give the latest status.

The sales activities and related customer feedback did also confirm the advantages of the validation and design approach to achieve world class performance while maintaining a robust design base and ensuring low complexity, like the on-board air cooled design. Besides the high operational flexibility – key for the European gas turbine market – it became also obvious that the SGT-8000H design allows for a comparable lean and simple approach of integration this gas turbine into a plant, giving advantages with regards to footprint, hardware needs, execution and commissioning time as well as maintenance efforts. Also the related impact on the business model of a typical European customer will be covered.
Introduction

The European power market has changed drastically in the past years, especially when looking at combined cycle power generation. From base load / cycling operation the operational profile of many plants has changed to high cycling or daily start stop operation; longer periods of stand still are observed for a growing part of the fleet and some units have even been mothballed.

Reasons for this change are the partly unregulated and uncontrolled addition of renewable power, low coal prices in combination with low CO₂ certificate prices as well as reduced power consumption due to energy saving policies or the financial crisis in Europe. In a recent interview the CEO of E.On, Johannes Teyssen, stated that “for E.On in general there are no significant profits to be made from conventional power production in the future; these would come mainly from ancilliary services.” [1].

On the other hand there is the obvious need for future addition of new gas fired generation capacities to compensate the fluctuating renewables and replace old fossil generation that has reached its (often already largely extended) lifetime. Part of this will come from small distributed generation but a significant part will be large scale combined cycle plants. Upcoming regulation with regards e.g. to capacity markets does of course play a significant role.

As OEM or EPC contractor the understanding of the actual customer and project needs is of utmost importance to be successful in such a rather volatile market environment. However, there are always three main needs for such new generation projects:

1. Stable business case: The business case of a new project must be set up properly, reflecting the individual project/market boundaries incl. some variances of these.

2. Short term financial security: When signing the contract of a generation project the customer/investor(s) needs to be sure that the contractual obligations like performance, functionality or timeline are met. In a volatile market already a small deviation from the expectation can result in significant losses from day one on.

3. Long term financial security: Especially large generation projects are big assets that need to maintain their value by ensuring long term revenues. This means e.g. maintaining performance levels, low maintenance cost, some upgradeability to maintain competitiveness etc. – topics which obviously can be somewhat contradictory to the afore-mentioned item.

The following sections will show how the Siemens 8000H portfolio serves these needs.
The Siemens SGT-8000H

The SGT-8000H series was from the very beginning intended to not only overcome the achieve more than 60% combined cycle efficiency but also to meet flexibility requirements while maintaining the robustness and reliability of the existing design heritage – which meant e.g. avoiding the application of risky new technologies.

By today – 6 ½ years after first firing the new engine, after 3 years of commercial operation of the first commercial installation and by June 2014 a fleet of 9 engines in commercial operation – it is fair to say that the Siemens SGT-8000H really has met all its targets – to the satisfaction of our customers and their stakeholders.

However, such success does not come by coincidence. Indeed it is the outcome of a longterm effort and several hundred million Euro investment of Siemens and many of its dedicated employees [2]. This reflects the major undertaking that an efficiency increase of about 2% points compared to previous design actually represents - especially when given the boundary condition to mainly optimize existing design features and not include major “game changer” technologies like steam cooling or significantly increased firing temperatures in order to limit the product risk. Still, history shows that any new gas turbine introduction came with significant risk irrespective of all the know-how that was fed into the development. And when rolled out directly to customer sites, this introduction risk did also hit those early customers – as a result of which there is compared to the 90s and the F-class introduction a much higher risk aware-
ness and averseness in the industry. Siemens decided for this reason to go for a full inhouse validation of the SGT-8000H series.

In fact, only after the SGT5-8000H had proven to be reliable after an intense 1.5 years testing phase, the 8000H series was released for commercial sales activities.

Siemens also applied this rigid “keep the risk inside” approach to the scaled version SGT6-8000H. Despite application of the typical scaling rules, all the available knowledge from previous engine scalings, the decision to use the same combustion system - it’s a fact that scaling faces limits. This is especially the case in the high risk section of a gas turbine, the hot gas path. So e.g. coating thicknesses cannot be scaled; cooling air pat-
terns/schemes and the realed (inner) structure of turbine vanes/blades need adaption, manu-
ufacturing is different (e.g. casting process) – to name some more obvious examples.
The result of this huge undertaking is a new gas turbine product line that has proven its ad-
vantages regarding flexibility, performance and robustness in (at the time of writing) 5 real
commercial operating units.

It needs also mentioning that the Siemens SGT5-8000H was the first gas turbine to power a
commercial project exceeding 60% plant net efficiency, demonstrating a still unmatched
world record efficiency of 60.75%.
The customers Business Case

The establishment of a fitting and stable/robust business case is key to a plant owners future success. Typical input parameters to such calculations are gas prices, revenues from electricity production, CAPEX, OPEX, performance/efficiency, reflected on a yearly basis in order to capture the financial outlook. Some parameters are put into weighted load cases representing the anticipated operation regime, considering also possible additional revenues from ancillary services like offering of frequency response capability. Major changes will result from adding a topic like district heating or process steam extraction (which e.g. seems to be currently the only way to be able to make a positive business case for a combined cycle plant in Germany). Of much importance to the business case is the reflection of the projects financial risks (see later sections).

In order to check the robustness of such a business case, scenarios via parameter variations for future years are conducted to assess (possible) changes in market/project boundaries. The business case will be reflected in the actual project specification as well as in the evaluation model - on which basis the customer then can evaluate the received offers, negotiate and finally choose the best fit for his project.

The advantages of an 8000H compared to F-class design is reflected in CAPEX (economy of size) and performance/efficiency while not compromising on flexibility.

The value of flexibility

A hard topic to be reflected in a business case or an evaluation model is the “value of flexibility”. It’s an easy decision for a project to ask for flexibility. But when it comes to the point where (additional) flexibility would actually come at an additional price tag it becomes very hard to assess if such an additional price tag does have a positive business case. This is especially the case if the added value is only a potential for the future –discussion then very fast tend to have a philosophical touch. To give some actual examples:

- In the US it is common practice to have supplemental firing in the HRSGs in order to be able to declare higher capacity and receive respective higher capacity payments. If actually operated the efficiency of the plant drops; also the steam tail is overdimensioned, reducing the efficiency in normal operation compared to a standard cycle; and there is higher first time cost. In Europe supplemental firing has not yet been assessed
positively but might be if there is a change towards a capacity market. However, would it make sense to include this in a project today?

- Within the typical European boundaries a plant will generate profit only when operating higher than about 50% load. So what is the value of operating in the “loss zone” at lower loads for longer periods of time compared a shutdown with the risk of a failed/delayed start when having declared capacity?

- Fast start capability. For declaration of e.g. secondary requency response capacity a typical threshold is the power reached at e.g. 15min after having received the signal to deliver. Fast start capability of course increases this power value and thus increases revenues. However, typically fast start capability is linked to a hot start. What is it worth to e.g. extending the allowable downtime for a hot start? How to assess a possible negative impact of e.g. increased steam cycle lifetime consumption for fast starts?

As an OEM with deep plant design knowledge Siemens can assist in finding answers to such questions and also have a technical solution available if needed – either now or retrofittable at a later point on time. Regarding the 8000H product portfolio above items and much more are available, starting from the core component over the complete turboset and its auxiliaries up to a full tailored turnkey scope, making Siemens as partner and the 8000H as core component the first choice for any new large generation project.
Short term financial security

With the liberalization of the energy markets and the appearance of IPPs there came an increased focus on the short term financial success of generation projects. While public and state owned utilities had mainly the long term energy supply security in mind, a power project of an IPP is an investment that has to deliver a secure return of invest also short term. Along with that came the need for low first cost that drove standardization and savings from repetition rates.

Nowadays – in a volatile environment where e.g. political rulemaking is not foreseeable long-term – the focus on short term security of invest and fast return of invest might become even stronger. Main drivers that may jeopardise the short term financia ls for a power project are:

- Delayed Commercial Operation Date (COD).
- Unscheduled interruption of operation and duration of the interruption (Unavailability)
- Deficits in the main deliverables like performance or other functionalities with direct impact on revenues and profit

To limit the risk exposure, these topics are covered via guarantees and respective liquidated damages payment schemes in the supply contract with the EPC/OEM. The remaining risk can partly be covered by insurances (like delay in startup DSU or business interruption insurance). However, LDs are capped and insurances have deductables, so there is always a remaining risk upon the plant owner/investor(s). So e.g. the waiting time for a prototypical high performance gas turbine DSU insurance easily goes up to 120 days – compared to 45-60 for a proven F-class product. Similar effect can be seen in e.g. business interruption policies, not to speak of higher premium rates for such insurances. These differences can easily sum up to a high two-digit to low three digit Million Euro risk in a commercial project – which – after deducting the possible LDs - will leave a significant two-digit Million Euro remaining risk to the plant owner.

Looking at the history in the industry (e.g. introduction of the F-class engines in the 90s or other more recent product introductions) there have always been issues on new products or product upgrades. Regarding the short term financial view especially the so-called “infant mortality issues” on new designs bear a high risk to a plant owner when applying such a product as an “early adopter”. In the long term issues have been (and will get) solved, but the short term losses due to late handover or unscheduled/extended downtimes have then happened already.
Well aware of this situation Siemens decided for the 8000H to go the path of a) staying designwise in the existing experience range to reduce the design risk, b) applying specific design features to reduce downtimes in case needed, c) conduct a rigid prevalidation on the new design features [3] and d) conduct full inhouse validation tests [3,4] on a complete engine with commercial sales release only after final testing of the unit, as outlined above - so it was ensured that even the very first customer would get a matured product that incorporated already the possible short term learnings.

History shows that the main focus/risk is in the compressor design and the hot gas path, mainly in form of hardware integrity risk; for the latter one also adding more risk due to long redesign/manufacturing timelines. Regarding the compressor Siemens did a full scale test of the 8000H compressor on a modified 5000F engine in the Berin Test Center (BTC) before even building and testing the SGT5-8000H prototype engine, including e.g. off-frequency testing. Regarding the hot gas path the decision was not to leave the firing temperature experience of the G engines, where Siemens has 24 units in operation with in the meantime >1 Mio fired hours. The SGT5/6-8000H test phases did then confirm the robustness of the design. Still, in order to reduce the risk of unplanned standstill before or after COD, the SGT-8000H design does incorporate several features to minimize downtimes in case needed: the compressor rotating blades can be replaced w/o a rotor lift; all turbine vanes and blades are replaceable w/o a rotor lift; the HCO system (see below) avoids rubbing of the turbine blades and related hardware integrity risk. Furthermore, concentrating on the highest risk areas in the hot gas path, turbine stage 1 and last stage blade is replaceable w/o a cover lift. Stage 1 has the highest thermal loading, so if there is a design/lifetime issue requiring unplanned outages, it will most probably come from this location. The turbine blade 4 is bearing additional integrity risk for a GT in the power range of the 8000H, as the massflow is increased compared to F-class, resulting in significantly longer blade length.

Regarding the performance, the 8000H has only been offered after a thorough validation, so guarantees for even the first commercial customers had been backed up with real full load engine data. With 9 units in commercial operation it can be stated that the performance test results of all these units were meeting the given guarantees. This also applies for the difference between new and clean (theoretical) performance (often used for evaluation) and the actual degraded performance at time of performance-test resp. the average performance over the operation period.

In order to control/reduce degradation itself the SGT-8000H series incorporates the patented Siemens Hydraulic Clearance Optimisation (HCO) System.
One of the major drivers for degradation are the clearances between stationary and rotating parts in a gas turbine, mainly in the turbine section. Due to faster thermal response of the rotor, especially during the start-up of a GT, the clearances get reduced and even rubbing may occur. As a result, this transient state normally defines the width of the clearances for thermally stable operating condition. With the HCO system a Siemens GT will have large enough clearances to avoid any rubbing in the turbine. The system will then push the rotor a few mm’s towards the compressor end during stable condition, reducing the turbine clearances due to the conical flow-path to the design width, ensuring the desired GT efficiency while avoiding the related degradation effect. Especially in the European Market, where customers are considering up to two starts per day, the HCO System represents a major advantage, avoiding starts-driven turbine degradation.

The gas turbine has also a direct impact on the surrounding equipment like auxiliary systems or the bottoming cycle design. The design of the SGT-8000H series, with e.g. a pure on-board cooling system design, did also focus on minimizing the additional systems around the gas turbine; in fact the 8000H did not introduce additional systems compared e.g. to a 4000F, thus adding no additional complexity to the plant design. This approach allows e.g. for minimizing the commissioning times by avoiding time-consuming on-site interface optimization e.g. between gas turbine and water steam cycle.

The result of this deliberate design and validation effort of the 8000H is reflected in the commercial projects. All 8000H projects so far have been handed over on or before schedule; contractual performance guarantees have been met and no unplanned outages had to be carried
out in commercial operation. With almost 3 years in commercial operation on the lead unit also the lifetime prediction in the hot gas path could be assessed, confirming the service intervals on the 8000H.

As a conclusion, the specific design features, the validation and market roll-out approach as well as commercial experience reduce the risk for a SGT-8000H project to levels comparable or even below mature F-class level, ensuring the short term financial benefit for the project owner(s).

**Mid to long term financial security**

Large generation projects represent large assets with huge 3-digit million figures of long term fixed capital. To go for such an invest it is crucial to focus on the following main topics:

- maintaining functionality and performance
- ensure low maintenance cost and service downtimes
- maintain competitiveness in the market (e.g. merit order)

The Siemens 8000H product line is designed also to serve these needs. The Siemens HCO system (see above) is a unique feature to ensure low degradation over the lifetime of the gas turbine, protection clearances even for fast starts. This system ensures low power and efficiency degradation over the whole lifetime of a plant, easily summing up long term to a two-digit Million Euro additional revenue figure in case for a 8000H-sized plant. And compared to other methods of turbine clearance control, the HCO system does not add any complexity to the plant. Being fail-safe it also does not bear the risk of malfunction and consequential unplanned degradation effects.

In general the SGT-8000H design does not add complexity to the plant in form of additional systems, vessels or other equipment compared to e.g. a 4000F. Looking long term, every system has to be maintained and serviced, can fail and lead to downtimes and repair efforts. While the typical long term service contract does cover the gas turbine, possibly steam turbine and generator, the responsibility for all other systems will go over to the plant owner after the warranty phase. In the long term any (additional) hardware will amount to a significant effect in the business case of a plant owner by increased maintenance cost and lost revenues due to unexpected downtimes.
One great feature of the SCC-8000H power plant solutions is its design for serviceability, going far beyond the service of the turboset alone. More than two decades of Siemens combined cycle power plant design in combination with many O&M customers lead to a deep knowledge within Siemens, how to actually design a plant such that every aggregate, system or measurement location can easily be accessed and maintained. In combination with preventive or condition based maintenance schemes this gives a long term advantage to the plant owner. A prominent example is the Siemens single shaft layout. The generator bus duct is routed out of the turbine building in parallel to the air intake, keeping the main turbine hall free of obstacles for safe crane operation, ensuring much lower downtimes at much less risk to the owner.

Besides the plant design the maintenance features of the gas turbine itself of course also ensure low service downtimes – not only in case of scheduled maintenance but especially for unscheduled service activities. Apart from the blade path features as outlined above the unique Siemens rotor design actually allows rotor maintenance to be conducted on site. Due to the rotor assembly with a central tie rod and self-centering rotor discs with Hirth serration (see picture), the rotor can be destacked on site and put back into the engine without the need for shipment to a factory and test-run in a balancing pit. This eliminates the need to secure a spare
rotor for avoiding long months of downtime. The rotor-destack feature has been proven on the 4000F fleet – still for a reality check, after the prototype testing in Irsching Siemens did a complete rotor destack on site. This served to test the tools, establish procedures and train personnel to do such maintenance.

Another aspect in a long term perspective is upgradeability. Looking at plants that have been built one or two decades before, there have been big advancements, e.g. for efficiency. One part of this advancement of course was introduction of new frames (like F or H), but at the same time the frames itself evolved significantly. For the future the efficiency steps might get smaller but for sure there will be further advancements. Looking at existing units this means that they will become less competitive over time compared to future generation projects. To counteract this there needs to be an upgrade strategy. Siemens has always followed the path of...
evolutionary design advancements that are applicable also to the previous design status; as a result all Siemens customers were always in the position to improve their existing plants if indicated. The SGT-8000H series will follow this same path. Regarding the plant design, however, the question of upgradeability is more complex, as a typical efficiency upgrade often comes with a power increase. One could assume that this will counteract the power degradation effect, but in fact the power increases often have been bigger than that - which means that some growth potential needs to be built in an actual plant. Unfortunately growth potential comes at additional cost due to e.g. slightly larger equipment than actually needed for the initial plant rating. So this needs some deeper thoughts, as in this case the long term perspective (more OPEX-driven) is in opposition to the potential short term benefits (more CAPEX driven). Given the experience and knowledge of combined cycle plant design, operation and cost structures, Siemens here can of course assist as partner for discussion and potential evaluation. The Siemens SCC-8000H plant solutions will represent already a life-cycle-cost optimised solution, including the relevant upgradeability.

Finally, looking long term also the gas turbine service parts availability is of great importance. Siemens has since many years 6 large gas turbine frames in the portfolio: SGT5/6-2000E, SGT5-4000F, SGT6-5000F, SGT5/6-8000H. This limited number of frames as well as the evolutionary design upgrade approach limits the variety of spare parts to be stocked from Siemens side to serve the fleet for scheduled and especially unscheduled maintenance. As a result Siemens has at any time enough spare parts available to serve any customer with needed parts, again ensuring low downtimes for unlikely but still possible events.
Summary

The Siemens 8000H program was from the definition of the design targets to commercial rollout and beyond intended to present a minimum risk and maximum value to the customers.

- Limited design risk by staying within known boundaries e.g. with respect to firing temperature and not adding major technologies as game changers while also not adding plant complexity compared to F-class design.
- Intense parts/subsystem prevalidation and full in-house validation for the SGT5-8000H before even starting commercial sales activities, followed by full in-house validation of the true scaled SGT6-8000H - all this efforts ensuring that the first customers will see already a matured design, drastically reducing the risk of delayed COD or early outages for eventual design rectification activities.
- Applying design features to minimise downtimes in the high risk areas of a gas turbine – just in case unexpected learnings beyond the validation experience might occur, thus further minimizing the customer risk by reducing the related downtimes.

The design and the rollout of the Siemens SGT-8000H series can be considered as the benchmark in the industry compared to earlier product introductions with

- all commercial SGT-8000H projects handed over on time
- all performance guarantees met
- all commercial units running reliably w/o forced outages.

the Siemens 8000H series can be considered the first successful H-class on the market. The minimized technology application risk at proven flexibility and performance and thus the reduced complexity and prediction inaccuracy of the economic evaluation model is a large advantage for power project developers. Given the rather volatile market environment this makes the SGT-5-8000H the best fit for combined cycle projects in Europe when considering the financial benefits & risks of such projects – for both short term and long term view.
Abbreviations

BTC  Berlin Test Center (gas turbine prototype testing facility)
CAPEX  capital expenditures
COD  -  commercial operation date
DSU  delay of startup (insurance)
EPC  -  Engineering, Procurement, Construction (company)
HCO  -  hydraulic clearance optimization (system)
HRSG  heat recovery steam generator
IPP  Independent Power Producer
LD  liquidated damage (payment)
OEM  Original Equipment Manufacturer
OPEX  operational expenditure
O&M  Operation and Maintenance (contract)
SGT  -  Siemens Gas Turbine
SCC  -  Siemens Combined Cycle
1S  -  single shaft

References
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