The flexibility of Siemens heavy duty GTs serving the European market needs

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Abstract

In the light of existing CO₂ reduction policies and related addition of renewable energy the European Power Market is in a general need for highly flexible fossil generation, especially for heavy duty gas turbines and related plants.

The term flexibility can have various dimensions in this context.

- There is the need to react on fluctuating renewable infeed, which is addressed by ramp rates, start-up times, emission compliant load ranges or frequency response capabilities.
- Of less obvious importance is fuel flexibility: From demand side the predictability on the gas consumption is getting lower, which impacts the gas supply contract schemes. So instead of long term contracts plants might in the future look towards short term contracts or even sometimes just buy gas on time on the spot market. Technically this results in the requirement to fire a broader bandwidth of gas compositions from different suppliers. At the same time on supply side the fuel composition bandwidth will also be increasing when considering LNG infeed, H₂ or synthetic Methane production (from energy storage, “power to gas”) or fracking gas (which significantly changes its composition over the lifetime of a project) – to name some prominent examples.

This paper will discuss the current market conditions and its implications on aforementioned flexibility capabilities and relate them to the Siemens offerings for heavy duty GTs and plants.
European Power Market Challenges

With the acknowledgment of climate change and its connection to CO₂-emission the European power and energy market has seen a fundamental transition. This was initiated by both EU-led legislation (like CO₂-trading scheme EU ETS) as well as by isolated activities on individual country level. The result is an ever-changing power market that has produced many desired but also a lot of undesired effects.

From global perspective the EU is on track to meet their 20-20-20 target setting [1]:

- a 20 % reduction of the EU's GHG emissions compared to 1990
- a 20 % share of renewable energy sources in the EU's gross final energy consumption
- a 20 % increase in the EU's energy efficiency

However, on country level the picture is mixed, with challenges for countries like Germany to meet their targets. With the power sector as a main contributor to greenhouse gas emissions e.g. the all-time low price for CO₂-certificates allows old fossil plants to run much cheaper than highly efficient combined cycle plants while producing easily up to double the amount of CO₂ per generated power with negative impact on meeting emission targets.

Besides GHG reduction there are also socio-economic targets (employment rates, poverty reduction, research and innovation plans etc.) that are to be considered by the policy-makers.

Regarding the power sector this translates into further challenges:

- to limit the cost increase for electric power for both industrial and private consumers
- to ensure adequate supply (system stability, reserve capacities)
- to distribute the burdens/cost sensibly between all players
- to promote innovations in the power market

The Siemens Answer

The Siemens position [2] in this respect is first of all that isolated activities of single countries can from an overall perspective have negative effects on the system, so it is deemed more favourable to have comparable regulations all across Europe. An example is the introduction of a CO₂-tax in UK, which immediately increased energy imports (and thus increases CO₂-emissions outside UK). Also individual capacity market schemes can have negative impacts by redirecting investments that are likely to foster imbalance regarding regional over- and undersupply.
In order to provide a guideline towards meeting 20-20-20 target setting while considering also secondary effects outside the power sector, Siemens has elaborated a 5-point plan [3] for a future market design. The starting point for these considerations was Germany but the resulting proposal can to a large degree be translated to the European Level (and actually also to other regions in the world with similar challenges and target settings). The core message is that a future market design must be a) based on competition and b) needs to allocate cost according to their cause. This can be achieved by the following approach:

1. **Feed-in responsibility:** Renewables market their electric power like other generators and feed into the grid “according to schedule”; no remuneration for power without demand
   - Ensure the concurrency of supply and demand

2. **Renewables allocation:** Support renewables based on their technological progress and with a regional differentiation
   - Cost efficiency and better management of new capacity installation

3. **CO₂ limitation:** The EU’s emissions trading system is strengthened; in addition, average CO₂ emissions might be limited for electric power generators or utilities
   - Greater investment security for low-CO₂ generation

4. **Reallocation of fixed costs:** System costs are allocated to consumers based on connected load; customers’ electric power rates vary according to the market price
   - No free-riding through partial self-sufficiency and allocation of costs by cause

5. **Winter reserve:** Winter reserve will be retained in the short term, so that a decision can be made on the introduction of a capacity mechanism in the medium term.
   - Affordable energy supply security with low regulatory risks

Regarding the third item there has been progress already, as it was decided to postpone the auctioning of 900 Mio CO₂ allowances to address the imbalance of supply and demand that led to the current low certificate prices. However, this measure will not be enough to reduce the estimated surplus of 2 billion certificates currently observed.

It is quite obvious that all these points would affect many Siemens customers in various ways and were not all taken positively. However, in this respect Siemens holds the position that as a large global enterprise we do not only have responsibility for our customers but also have to care for the society we are part of as well as the costs and effects that energy policies have on the overall economy. Above plan is one contribution to live up to such responsibility.

Regarding large combined cycle generation the plan would help to open brighter prospects for the future - for both existing plants and new projects. What these will have in common is the need for high flexibility of such generation assets in a future world of increasing share of intermittent renewables – and that Siemens has the answer to these needs. The possibilities for retrofitting flexibility is covered in a separate paper (“From Base to Cycling Operation - In-
novative Operational Concepts for CCPP” [4] while this paper will focus on the Siemens portfolio for future new-build projects.

The Siemens heavy duty GT portfolio

For the European 50Hz grid Siemens offers three heavy duty frames: SGT5-2000E, SGT5-4000F and SGT5-8000H, with the standard turbotset and plant portfolio spanning a power range from 172MW to 1200MW.

Historically the SGT5-2000E is the application for smaller power needs, fast installation time, open-cycle peaking and off-spec liquid or gaseous fuels with high contamination; as a result this engine plays only a niche role in the Central European Market. This is opposite to the SGT5-4000F that has been dominating the European Market for more than a decade with a multitude of installations all across the continent. And of course there is the latest model, the SGT5-8000H with significantly higher power density and efficiency compared to F-class. Both 4000F and 8000H have an excellent position for meeting the European Market needs, however the 8000H with advantage for larger projects, higher fuel prices and longer operating hours p.a..
The SGT5-4000F

With 115 units sold in Europe alone, this well known gas turbine is the best selling large gas turbine in the European Market. Since its market introduction in 1996, the machine has seen continuous development [8], resulting in an impressive power increase from initially 240MW to in the meantime 307MW for the latest version. And development efforts continue, benefitting both existing and future customers. At the same time the current models offer far more reliability than the initial model with today’s fleet average exceeding >99% since years, making the SGT5-4000F the F-class benchmark in the industry also in this respect. Besides performance improvement also the operational flexibility has been focus of recent years. Based on the inherent design advantages (rotor, design, HCO, turbine cooling - see below), improvements in many aspects (fuel flexibility, load gradients, turn down etc.) have been made.

As a result a SGT5-4000F will safeguard the plant investment and competitiveness of any project for years to come.

So even if many projects in Europe are discussing H-class nowadays, for those projects where a 8000H would not be the best fit – be it from footprint, economics, financing, grid connection or other reasons – the SGT5-4000F is the best available choice.
The SGT5-8000H

The Siemens 8000H series marks the top of the Siemens portfolio with high power outputs of 600MW and above in CC application and allowing for net efficiencies far beyond 60%.

This GT series was from the very beginning intended to not only to achieve unprecedented efficiencies 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.
Today - after 4 years of commercial operation of the first commercial installation and a fleet of 16 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 [5]. 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.

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 rolling out a new product directly to customer sites, this introduction risk does hit those early customers. As a result of this there is - compared to the 90s and the F-class introduction - a much higher risk awareness and averseness in the industry today. Siemens decided for this reason to go for a full inhouse validation of the SGT-8000H series for both 50 and 60Hz Versions.

In fact, only after the SGT5-8000H had proven to be reliable after an intense 1,5 years testing phase- including a 1200hr full load run to capture at least some information on durability- the 8000H series was released for commercial sales activities.
The result of this huge undertaking is a new gas turbine product line that has today proven its advantages regarding flexibility, performance and robustness in commercial operating units around the globe:

- The Siemens SGT5-8000H was the first gas turbine to power a commercial project exceeding 60% plant net efficiency, demonstrating a world record efficiency of 60.75% already in 2011 and with further projects all meeting high CC efficiencies of up to 61%.
- All commercial projects so far have been handed over on schedule (including fast track projects with 24 month execution time), with many projects handed over even ahead schedule.
- The fleet is running stable with 5 units having achieved already more than 10,000 operating hours and with the overall fleet soon to cross the 200,000EOH mark.

The track record impressively demonstrates the capability of the 8000H series. A further display of the capabilities will soon be demonstrated at the German Lausward CHP project, where the 8000H will again set new benchmark levels for performance and efficiency.

**Operational Flexibility**

The Siemens SGT5-4000F and SGT5-8000H share some common design features that allow for inherent operational flexibility:

**Rotor design**

The Siemens heavy duty gas turbine rotors consist of individual discs being spanned to a stiff rotor by a central tie rod. The individual discs are aligned with the so-called Hirth-serration on their interface areas which allows for a) self-centering of the rotor discs during assembly and b) high torque transfer through the rotor while avoiding individual discs slipping and resulting rotor imbalance (e.g. in case of grid faults).

This rotor design also allows for internal cooling air passages from compressor to turbine section, which ensure fast thermal response of the rotor in case of high load transients, fast cold starts and alike, basically eliminating the lifetime impact on rotor for such operation.

**Hydraulic Clearance Optimisation HCO**

One of the major concerns for flexible operation with fast load transients 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 - with impact on performance (degradation) and potentially also
hardware integrity. 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 for startup. During stable condition the system will then push the rotor a few mm’s towards the compressor end, reducing the turbine clearances due to the conical flow-path to the design value. So the system avoids the effects on degradation and hardware integrity. Especially in the European Market, where customers are considering up to two starts per day, the Siemens patented HCO System represents a major advantage, avoiding start-driven turbine degradation.

**Turbine Cooling**

Both 4000F and 8000H frames employ a full self-sustaining on-board cooling air system, meaning cooling air is extracted at the appropriate compressor stage and directly routed to the turbine; there are no cooling-air coolers required, no interfaces to BoP/HRSG exist. Besides advantages in project engineering and execution (less complexity, less hardware) this approach ensures that no interdependencies to water-steam-cycle condition will limit the operational flexibility of the GT and the plant. Also plant control has much less parameters to take care of when operating with high load transients.

The 4000F and 8000H operational flexibility is displayed in the following graph. All relevant requirements for grid support operation, from fast (cold!) starts as tertiary reserve over high load transients and low turndown for secondary to fast primary reserve are meeting or exceed-
ing the grid requirements, making a Siemens Combined Cycle application the perfect fit for all European market needs:

It is important to note that the gas turbine capability alone is not sufficient. The whole plant - turboset, I&C system, auxiliaries, HRSG etc. - needs to be designed to cope with such capabilities. As a result, Siemens plant solutions has developed corresponding plant operation concepts.

FACY (FAst CYcling)

This feature combines a set of engineering ideas into a single integrated plant concept with the aim to design a plant for an increased number of starts and to reduce startup times. If possible, no limits were to be placed on the gas turbine by other power plant components, such as the heat recovery steam generator or steam turbine, during a hot and warm start. FACY reduced startup times for a hot start from 100 to about 55 minutes.

HOF (HOt start on the Fly)

In the course of the FACY development areas came to light in which further optimization could be achieved, which were implemented in a second generation concept. The major improvement is the startup procedure. Hold points at which a plant waits until certain steam parameters have been reached were eliminated as part of the shortened "Start on the Fly" startup procedure. The steam turbine is now started up parallel to the gas turbine using the first steam which becomes available after a hot start, reducing the start-up time to below the 30-minute mark (see graph below).
Shortening startup times and improving the starting reliability while increasing the number of starts is only one of many requirements regarding plant flexibility. Those with respect to grid support, have seen the tendency to become more rigorous due to the continuously increasing percentage of renewable resources on the grid. A special challenge arises from the following topics:

- Load stabilization at low frequencies
- Primary and secondary frequency response
- Island operation capability

The Siemens plant concepts include the technical features to meet such requirements without compromising efficiency, thanks to an integrated approach to combine the potential of several systems and components in a single solution with an optimized I&C closed-loop control concept.

The 4000F capabilities and related plant concepts have been demonstrated in various applications already. On the 8000H the flexibility needs were a main design target for gas turbine and plant design and have been thoroughly validated. Below some real-time plots demonstrate some challenging operation modes: primary frequency response and grid islanding to stable low part load.
As mentioned above the challenge for such operation modes is not on the gas turbine alone but the whole cycle needs to be designed for and controlled to such capabilities. Above figures demonstrate the capability of the 8000H plants, based on the Siemens EPC experience, employing design features like the Siemens proprietary Benson boiler technology.

**The value of operational flexibility**

In Europe combined cycle plants need flexibility. However, it is quite hard to define the “value of flexibility”. It’s easy to ask for flexibility, but there is always the point where (additional) flexibility will come at additional cost – and then things get complicated. 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, because 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% part load level. 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? Is it worth the additional efforts/cost to have lower turn down capability?
• For declaration of e.g. secondary frequency 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 e.g. the value of extending the allowable downtime for a hot start? What is it worth to reduce the negative impact of e.g. increased steam cycle lifetime consumption for fast (warm and cold) starts?

As an OEM with deep plant design knowledge Siemens can assist in finding answers to such questions and also provide a technical solution available if needed – either now or retrofittable at a later point on time. Regarding the 4000F and 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 the first choice for any new large generation project.

**Fuel flexibility**

In general heavy duty gas turbines are fired with either gaseous or liquid fuels (oil #2), the latter typically only as backup fuel. In Europe - e.g. due to the large grid - the requirement for liquid backup fuel capability has historically been low. For the future there are no signs that this will change; the new emission ruling in preparation seems to target for 25ppm NOx for liquid fuel operation, so such operation modes will be even more unlikely sought after in Europe. Consequently the focus in Europe for large CCPPs is and will be on gaseous fuels.

The traditional sources [6] for gas in North/Northwestern Europe are (besides lots of smaller local sources) of course the North Sea and Russia. These gases have always been characterised by high Methane content and low inertia content (socalled H-gas, Wobbe range 46-56 MJ/m³). One exception to this rule are large gas fields in northern Germany and the Netherlands with socalled L-gas quality (Wobbe range 38-47 MJ/m³), characterised by significant N2-content of up to 20%.

In Southwestern Europe/Turkey the supply is from Russia and the region of the Caspian Sea, typically H-gas range. In Southern Europe the core supply comes from North Africa (mainly Algeria) via Gibraltar or Sicily, also H-gas quality.
Besides these pipeline gases the import of LNG is a main pillar of Europe’s gas imports (14% in 2013) [6]. Again this in mainly H-gas quality with Wobbe-range from 48-52MJ/m³ but with sometimes increased content of Ethane/Propane/Butanes. See graph (from Eurogas) for sources.

For the future this landscape will change mainly by three contributors:

a) The flaring of associated gas has become a focus area for the fight against global warming, so it will increasingly be available as additional source. In the light of enhanced oil recovery it is to be expected that the inertia content of associated gas will increase with time

b) Infeed of fracking gas into the pipeline system

c) Mid to long term H₂ admixture being a possibility of renewable energy storage
Regarding the gas qualities in Europe however, it is anticipated that the majority of supply will remain in the H-gas range (either by their original property or by fuel gas treatment) in order to keep the properties within the parameters of the existing gas supply and consumption infrastructure.

With regards to gas turbine capabilities large differences in Wobbe-range will have an impact on combustion stability and must be taken care of. Siemens heavy duty gas turbines always allow a Wobbe variation of +/-5% (“no questions asked”) but of course can support much wider ranges, e.g. running on H or L gas qualities. However, the Wobbe number is not the only driving parameter for combustion stability. So e.g. higher hydrocarbons (Ethane, Propane, Butane, H2 etc.) have significant impact on the reactivity (e.g. flame speed) irrespective of the Wobbe number and thus are directly influencing combustion stability. As a general statement it can be said that Siemens heavy duty GTs can cope with quite wide Wobbe variations beyond +/-10% but [8]. However, the aforementioned effects from individual components in the fuel gas demonstrate that statements based on pure Wobbe-Index can be misleading, so Siemens typically will always thoroughly assess the individual project with its boundaries; as a first step typically by fuel gas temperature conditioning only and as a second step also by adapting the burner hardware to the project specific needs.

While it is safe to say that Siemens gas turbines will be able to cope with the gas qualities in Europe, other markets as well as individual projects are demanding higher gas quality bandwidths. To foster the fuel capabilities of its heavy duty gas turbines, Siemens has just recently inaugurated a new combustion test center in Ludwigsfelde [7]. This addition to the existing test capabilities will ensure that future market needs can be addressed appropriately.
Abbreviations

- BoP: Balance of Plant
- CCPP: Combined Cycle Power Plant
- EOH: Equivalent Operating Hours
- EPC: Engineering, Procurement, Construction (company)
- EU: European Union
- EU ETS: EU Emission Trading System
- GHG: Green House Gas
- GT: Gas Turbine
- HCO: hydraulic clearance optimization (system)
- HRSG: heat recovery steam generator
- LNG: Liquified Natural Gas
- OEM: Original Equipment Manufacturer
- SGT: Siemens Gas Turbine
- SCC: Siemens Combined Cycle

References


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