Evolutionary development of Siemens SGT-800

A ground for reliable upgrades

Abstract

Product development in small steps (evolution) gives the advantage of fine-tuning the design based on available operating experience. Bigger leaps of the design (revolution) introduce a potential risk where undesired field issues may reduce engine performance or affect negatively the reliability and availability of the end users gas turbine units. The Siemens Gas turbine SGT-800 has been on the market for 20 years. During these years a number of steps have been taken in order to further improve the performance and the design still keep a high operational reliability. During this time extensive operational experience has been gained with approximately 7 million accumulated operating hours. But also design methodology such as software and computational power and modeling have advanced significantly over these years, giving the opportunity to further improve the design in respect of optimizing aerodynamics, cooling and component integrity.

When an updated design or a service schedule is released to the market also older versions of the SGT-800 are considered. This is made by launching service products where the latest design of components may be implemented on the existing fleet as well. One example is that the introductory rating of the first SGT-800's was 43MW and throughout the years the power rating has increased by some 35% to date. This has been made in seven steps where each step is based on the previous experience and feed-back. This gives the existing customers the opportunity to implement upgrades to increase power output and/or efficiency when a planned inspection is performed. Other example where the evolutionary design development has enabled customer values is increased availability by extending the standard time between overhauls. To further increase the time between overhauls also a tailored maintenance schedule is available. A reduction of the NO_x-emissions from an introductory level of 25ppm down to a single digit value by fine-tuning the combustor/burner design and control logic is also released. The SGT-800 has since the introduction had a very high operational reliability and thanks to the evolutionary development principle this important performance has been preserved (or even improved) over the years despite all the released upgrades of the unit.

Contents

Market requirements

The market development and requirements of the gas turbine business may be summarized in three major headlines: *optimized performance* and *reduced environmental footprint* and at the same time there is a requirement for a *high availability* and *reliability* of the installation which should not be jeopardized.

Naturally the original equipment manufacturers (OEM) of the equipment are putting a lot of Research & Development efforts in these areas:

Optimized performance – in order to get the most economical investment

- Increasing the output of an existing design is a common way to make the customer investment (first cost) more profitable since the investment cost in terms of $/kW will normally be reduced.
- Increasing the efficiency will reduce the cost for fuel where even a small improvement will have a significant effect of the operational cost since approximately 80% of the total cost of ownership is related to fuel cost.

Reduced environmental footprint – the emissions from power production units

- Reducing the CO_2-emissions by increasing the engine efficiency
- Reducing the NO_x, CO and emissions from unburnt fuel components by optimizing the combustion.
- Increasing the fuel flexibility to include H_2-combustion which is an environmentally neutral fuel since only H_2O will be emitted.
- Increasing the fuel flexibility to include heavier hydro carbons as well as inert gases – fuels that today maybe are flared off or utilized in less efficient systems/engines.

Availability/reliability – to stay in business installation should be available for

- Availability of the unit shall be high where a predictable maintenance program is in place and the time between overhauls are extended as far as feasible.
- Reliability shall be secured at a high level. This is required even when the utilization of the design is stretched in order to fulfill the market demands described above.

Meeting these challenges will require a careful development process in order to not compromise any of these important factors. One way to proceed with the development without making deviations from the key performances is to take small evolutionary steps each time a new higher rating is released. And where the re-design is based on the experience gained from previous ratings and where possibilities of further optimizations have been seen.

The SGT-800

Siemens in Finspong, Sweden manufactures industrial gas turbines in the load range from 19 to 57 MW (SGT-500/SGT-600/SGT-700/SGT-750 and SGT-800). The first gas turbine units produced in Finspong where the SGT-500's which came into the market in the late 1940's and is still available to the market due primarily for its remarkable fuel flexibility.

The development of the initial version of the SGT-800 was started in 1995 and introduced to the market in 1998. It is a single shaft machine mainly adapted for power generation where the performance/efficiency has been optimized for combined cycle applications.

The combustion system is of a patented DLE-design (Dry Low Emissions) which means that low emissions on both gaseous and liquid fuel are reached without any water or steam injection.

To date more than 350 units have been sold to all continents over those 20 years that the unit has been on the market and the operating hours have now accumulated to a total of 7 million. Today this is the market leader in its power range (40-66MW).

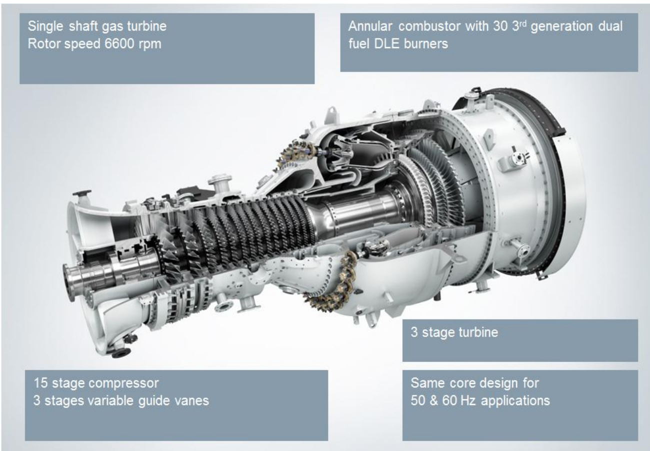


Figure 1: SGT-800 gas turbine, with dual fuel capability, single shaft unit mainly for PG applications

Evolution of the SGT-800

The basis for development and upgrades are experience and feedback which is a continuous process.

Design evolution

The evolution of the SGT-800 is based on four major corner-stones which all contribute to the enhancement of the design:

- *Prototype testing;* a number of heavy instrumented, full load/full speed prototype tests performed in test stand and at site giving clear views of the design boundary conditions.
- *Operating experience;* experience gained from long operation at sites where inspections and overhauls have been performed. More than 200 hot section & compressor inspections and overhauls have been performed and the number of borescope inspections is more than 300 of the SGT-800 fleet.
- *Software technology & computational power and model updates and calibration;* over these 20 years the engineering software has developed together with calculation capacity of the computers. This gives more accurate results of the calculations but in order to make well founded conclusions it is necessary to also have the right input data and boundary conditions. This is feasible thanks to the feed-back from the operating experience which makes it possible to calibrate the models based on actual feed-back.

Manufacturing & material properties; manufacturing procedures are developing as well as components materials and their properties. This gives further opportunities to optimize the design of the components. Two recent examples are 3D-printed components and new alloys with better resistances to oxidation, creep, corrosion and low cycle fatigue.

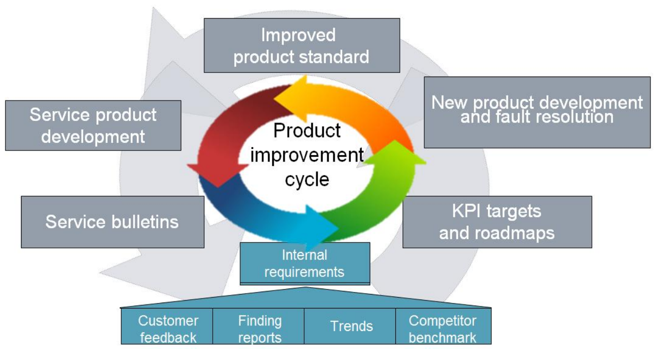


Figure 2: SGT-800 evolutionary development process

Keeping the basic design intact

The evolution is always based on the same basic design principles: same rotor speed, same amount of stages in the compressor and turbine section and the same type and number of burners. By keeping these basic design features it makes it possible to utilize the evolutionary developed components also on existing (older) units and to be installed as upgrades at planned inspections.

Optimized performance: Rating

Eight different ratings (output) have been available throughout the years – from the initial 43MW up till today's latest rating of 57MW. This corresponds to an average uprate at each step of approximately 2MW (or 5%). Together with the optimized design for increased output of the units an efficiency increase is also achieved related to optimized cooling of components and reduced losses in the design.

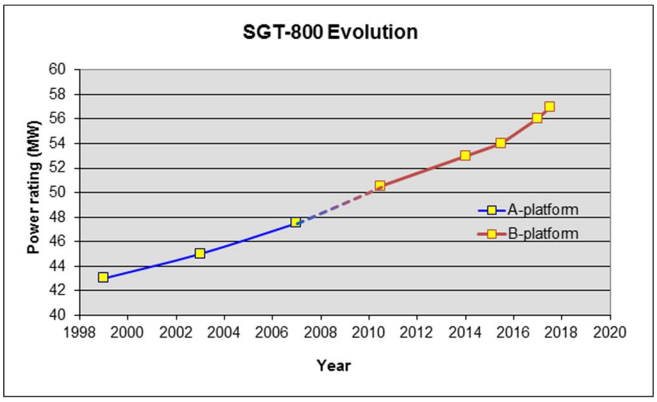


Figure 3: SGT-800 power rating evolution over time

There have been two versions/platforms of the design referred to as A- respectively B-platform. With the first A-platform there have been three power ratings: 43/45/47,5MW where the initial rating was considered as an introductory rating with some design margins to allow for an upgrade potential. In 2011, with the B-platform, the next compressor generation was released with increased air flow capacity and increased efficiency but with the kept air flow path. Blade #1 & #3 in the turbine were also modified related to the increased performance. Altogether there have been five ratings of this B-platform released (50.5/53/54/56/57MW).

Simple Cycle		"B"-platform ratings currently offered			
Power output	MW(e)	50.5	54.0	56.0	57.0
Electrical efficiency	%	38.3	39.1	39.6	40.1
Exhaust gas flow	kg/s	134.2	135.5	136.0	136.6
Exhaust temperature	°C	553	563	568	565

Figure 4: SGT-800 power ratings offered today – lowest rating now being phased-out

Reduced environmental footprint: Emissions & Fuel Flexibility

The combustion system in the SGT-800 is referred to as the 3rd generation DLE which is used also in the Siemens SGT-600 and the SGT-700 frames. Since this system is common in three different frames it means that huge fleet experience is gained from many various operation regimes. Both experience gained at different sites and engine validation load testing performed at the test stands at Siemens are fed back into the design resulting in expanding the approved fuel specification as well as further reduction of emission levels.

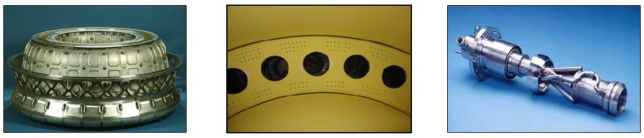
Gas fuel constituents	Max mole %	Comment
Methane, CH_4	100	
Ethane, C_2H_6	100	Certain conditions required above 30% Ethane level
Propane, C_3H_8	100	Certain conditions required above 30% Propane level
Butanes and heavier alkanes, C_4+	15	
Hydrogen and carbon monoxide, H_2 + CO	50	Certain conditions required above 10% Hydrogen level
Inerts, N_2/CO_2	50/40	
Hydrogen sulfide, H_2S	2.8	Revised maintenance program above 0.25% Hydrogen sulfide level

Figure 5: Latest fuel specification of the SGT-800

The initial fuel specification of the SGT-800 – some 20 years ago – was quite narrow and based on standard natural gas. Today a wide range of heavier hydro carbons, hydrogen and inert gases are accepted in the combustion system of the SGT-800.

The NO_x (and CO) emissions have been reduced over time. Initially 25ppm NO_x was offered but related to tuning of both the hardware and the software 15ppm NO_x can now be guaranteed. In certain cases even 9ppm NO_x can be offered including the latest knowledge and development efforts. On liquid fuel operation at 42ppm NO_x is offered without any water or steam injection.

Burner type	Fuel	NO_x @ 15% O_2	CO @ 15% O_2	NMVOC @ 15% O_2	PM10 (incl CPM)
Gas burner	Natural gas	≤ 15* ppmv	≤ 5 ppmv	1 ppm	1.5 lb/h
Dual fuel burner (15-20% of total sales)	Natural gas	≤ 15 ppmv	≤ 5 ppmv	1 ppm	1.5 lb/h
	Diesel No.2	≤ 25-74 ppmv	≤ 5 ppmv	6 ppm	3 lb/h



* 9 ppmv available with conditioned operation parameters

Figure 6: Emission levels on the 3rd generation DLE – latest design

Availability: Maintenance program

The initial maintenance program of the SGT-800 was based on 20'000 EOH (Equivalent Operating hours) intervals. From the operational experience and updated design this was later stretched to 30'000 EOH which is about four years of continuous operation.

Today, owing to the latest knowledge about the component degradation mechanisms and aging material properties, combined with monitoring of the operational profile and boundary conditions, further optimizations of the maintenance program can be made. Newly developed algorithms will predict the consumed and remaining life of each individual component of the unit.

Such tailoring on individual basis can be made considering customer preferences such as outage interval maximization, adapted calendar outage planning or optimize the replacement scope. Operating time between overhauls may be extended considerably beyond the standard 30'000 EOH in many cases.

This extension of the outage intervals combined with reduced downtime at each inspection will increase the availability significantly.

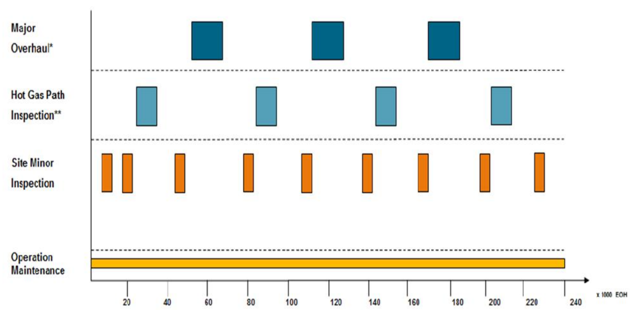


Figure 7: Maintenance program of the SGT-800 showing the inspections and overhauls up to 240'000 EOH (approx. 30 years) of the standard 30'000 EOH schedule

Upgrades offered at Service

As described above the evolutionary development principle enable implementation of later SGT-800 rating components to the existing (older) units of the SGT-800 fleet. The upgrades are preferably performed at a planned hot section inspection or a major overhaul (when the unit is opened anyhow) and can be performed on site (or at a local workshop) – with parts delivered from Siemens, Sweden.

These upgrades are communicated to the market both by distributed Service Bulletins and Users Conferences which are organized on a regular basis. Examples of upgrades available are summarized below.

Performance upgrades

- Upgrade from the 43/45MW performance up to 47.5MW. This is upgrade where the unit is still within the A-platform design and was released to the market in 2014. The airflow distribution is optimized according to the 47.5MW design also resulting in increased efficiency of 0.6%.
- Upgrade from the 43/45/47MW to 53MW has now been released. This means a larger upgrade where the design will be transferred to the use of B-platform components. Depending on the customer preferences this upgrade may be applied in different ways:
    - An additional power output to be in the 48MW range when most probably no or little upgrade is needed to the SGT-800 auxiliary system such as, e.g., the gear and generator. This rating is most favorable to also give extended outage intervals using Siemens Tailored maintenance called LTP-Flex.
    - An additional power output to be in the 48-53MW range to be adapted depending on customer needs and investment decisions to possibly upgrade also part of the SGT-800 auxiliary system plus the steam cycle of the combined cycle power plant. The higher output power will also come with a considerable efficiency and heat rate gain that will save up to 3.5% of fuel at full load and even more on part load compared to the original SGT-800 configuration.
- Upgrade from 50.5/53MW to 54MW. This upgrade is performed within the Bplatform and was released to the market in 2017. The components used in the 54MW design are implemented in the units with lower rating which will also give a corresponding efficiency improvement of 0.7%.

Maintenance program updates

- *Extended maintenance program;* in 2010 the standard maintenance periodicity for B-inspections (or hot gas path inspections) was extended from 20’000 EOH to 30’000 EOH. This was possible from the enhancement made in conjunction with the release of the 47MW rating combined with the experience gained from the fleet. This has since then been the basis for maintenance planning.
- *Tailored Maintenance Program;* released in 2017. Lifing algorithms have been developed for different SGT-800 configurations of components where consumed and remaning life of each component can be established depending on ambient conditions, load and other operating factors. This gives the opportunity to make a tailored maintenance program for the SGT-800 units, where the previous rigid EOH-based program can be replaced with a more flexible approach and components are used optimally.
- A number of digital offerings are available where collected data from the customer are used for analyzing the status of the unit and giving advice regarding planned service scope, remote inspection and operational support.

Emission and fuel flexibility updates

- *Combustion upgrades;* initially a typical emission guarantee was at a level of 25ppm NO_x. By utilizing the latest hard- and software this can be reduced to 15ppm NO_x
- *Advanced Emission Tuning;* the SGT-800 has used the same type of 3rd Generation of DLE-burner throughout the years. Emission levels are normally manually tuned at commissioning with a certain margin to combustion dynamics. From the extensive experience gained an automatic control was introduced in 2017 where feed-back signals from the dynamic pressure measurement are utilized for the burner control software in order to minimize the emissions. This will lead to lowest possible emissions at every operating point.
- *Fuel flex & H2*; the latest standard design will open the fuel specification for heavy hydrocarbons and inert gases as shown in Figure 5 above. By adopting the latest additive manufacturing methods (3D-printing) high levels of hydrogen content is possible.

Do the upgrades jeopardize the Reliability?

Already from the launch of the SGT-800 the reliability of the unit has been exceptionally high and since this is a strong market demand this has been a main guiding-star and should not be compromised. Due to this the evolutionary development is always based on previous experience as described above. The fleet operating statistics shows that the high reliability has been maintained at a very high level despite the fact several upgrades released to the market, both through new sales and as service products upgrades. The average value over the last nine years is close to 99.5%.

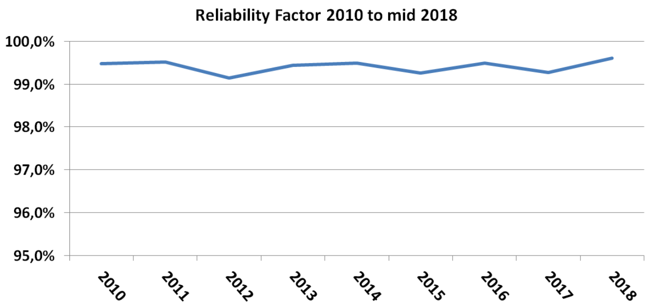


Figure 8: The SGT-800 fleet reliability last nine years

Conclusions

The SGT-800 has developed continuously during the last 20 years with an initial rating of 43MW. During this time frame seven up-ratings have been released – with an average output increase of 2MW with each new rating and a related efficiency increase – where each step taken is based in the operational experience gained from previous generations and adding the latest technologies and materials. By adopting the evolutionary development principle the number of surprises is minimized.

Siemens philosophy is that these evolutionary upratings should also be made available for the existing, installed fleet as after-market products. Therefore new upgrades and improvements are continuously communicated to the existing Service customers by Service Bulletins and at Users Conferences in order to give all the existing customers the benefits from the latest generation.

The SGT-800 has since the introduction maintained a very high operational reliability and thanks to the evolutionary development principle this will continue also when introducing and implementing new upgrades of the units.

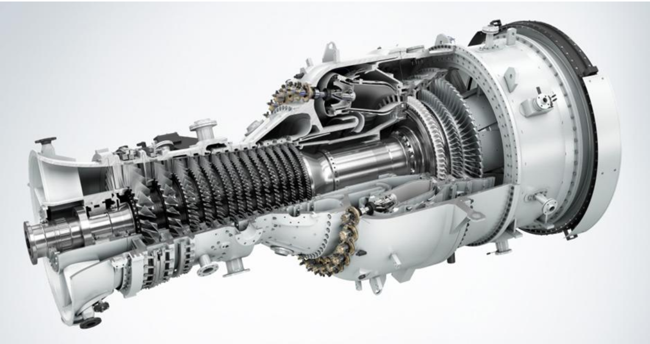


Figure 9: The SGT-800

Abbreviations

3D	Three-dimensional
°C	degree Celsius
CO	Carbon monoxide
CO_2	Carbon dioxide
DLE	Dry Low Emission
EOH	Equivalent Operating hours
H_2	Hydrogen
H_2O	Chemical formula for water, ice or steam
Hz	Hertz
kg/s	Kilogram per second
lb/h	Pound weight per hour
MW	Megawatt
NO_x	Nitric oxide
OEM	Original equipment manufacturers
PG	Power Generation
Ppm	Parts per million
ppmv	Parts per million volume
SGT	Siemens Gas Turbine
SIT AB	Siemens Industrial Turbomachinery AB (SIT AB)
$/kW	Costs per Kilowatt hour

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