Gas turbine performance and maintenance continuous improvement

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Abstract

To meet the dynamic market changes and to improve power plant competitiveness and profitability, OEM of gas turbines are continuously focused on their product development and improvement. Continued enhancement of existing OEM products and services is an important part of the OEM's integrated development concept. In this article the application of Siemens' product & services improvement concept is demonstrated on the example of the SGT-600 gas turbine. The 25MW SGT-600 gas turbine was launched on the market in 1984 and since then several modifications and upgrades have been performed, all of them as an answer to the changing market and customer demands on gas turbine performance, operation and maintenance. The following topics are discussed in this article: - emissions reduction; - extension of gas turbine life cycle and time between overhauls; - maintainability; repair of the hot gas path components; - remote monitoring and diagnostic. An overview of current Siemens R&D portfolio dedicated to further improvement of the SGT-600 fleet (e.g. flexible operation, part load operation, cyclic operation mode, new maintenance concepts) is discussed in this paper as well.

Introduction

The continuous improvement program of Siemens' gas turbines addresses performance, reliability, availability, operation and maintenance aspects. Together, performance and maintenance-related upgrades play an important role in power plants competitiveness and profitability improvement. The development and upgrade history of the SGT-600 gas turbine (see Figure 1) is an example of Siemens’ continuous product improvement strategy [1].

The first commercial operation of SGT-600 (originally known as GT10A) started in 1988. The rating at that time was 22MW.
In 1990 this engine was transferred from Sulzer Escher Wyss to the Swedish company ABB Stal (now Siemens Industrial Turbomachinery AB) and the first modification to be introduced was the
Dry Low Emission (DLE) burner with 25ppm NOx dry @15% O₂ on gas. Today the DLE burner is the standard design, but a conventional combustor can be delivered on request.

In 1992 a new mature rating (known in the market as GT10B) was launched. The turbine inlet temperature was increased by 50°C, as a result of which the rating was increased to 24.5MW@34.2% electrical efficiency. The next minor increase in output (0.5MW) was introduced in 1997. The power output increase was achieved by a minor increase of air flow through the engine (by re-staggering compressor stage 1 blades and vanes [2]).

In order to meet customer requirements for footprint, the size of the SGT-600 package was modified twice, first time at the beginning of the nineties and second time at the end of the nineties.

All design and systems modifications performed so far resulted in improvement of:

- gas turbine performance and operation (e.g. efficiency, power, reliability, start reliability),
- maintenance duration reduction (e.g. downtime reduction, maintenance scope minimization, maintenance tools improvement),
- maintenance cost reduction (e.g. repair instead of new parts, longer parts life, less field service).

Currently, a new SGT-600 upgrade is under development and addressing further emission reduction (to 15 ppm NOx), flexible operation (cyclic life-time extension), power and efficiency increase at hot ambient temperature, further extension of Time Between Overhauls.
Operating experience

Siemens has a solid process and tools to follow up and analyse gas turbine operating experience and statistics. The operating experience and operating statistics (defined in accordance with ISO 3977-9 [3]) presented below represents the current status of the SGT-600 fleet at the end of March 2013.

The current SGT-600 fleet accounts for more than 300 units. The total accumulated operating experience is more than 7 million operating hours, of which more than 5 million hours on DLE. The fleet leader has accumulated more than 160,000 operating hours.

The operating statistics: -Reliability Factor 99.5%; -Availability Factor 96.6%, Start reliability 92.4%, Mean Time Between Failures more than 2850 hours. The data for the operating statistics are based on the input from 35% of the SGT-600 fleet in commercial operation and include all types of applications and designs.

Emission reduction

The development of the DLE-burner started as long ago as the mid-eighties in co-operation with ABB. In 1986, a first generation DLE-burner was introduced with a NOx-level of 75 ppmv (dry). The experience from this development was used when designing the 2nd generation of DLE burner. In 1991 this burner was introduced specifically for the SGT-600 gas turbine and since then SGT-600 DLE has accumulated more than 5 million hours of operating experience.

The technology of the combustor is lean, pre-mixed fuel in a two-slotted cone/burner. The design is simple: it has no moving parts and only two control valves for pilot gas and main gas. No staging is used for the combustion, but the NOx-emissions are kept at a level of 25 ppm at full and part loads.

To achieve lower CO emissions at part load, a combustor bypass system (see Figure 2) is available as an option. Opening of the bypass valves means that the airflow to the burners decreases, the flame temperature increases and the CO emissions decrease. The bypass system keeps the flame temperature and the emission levels constant at 70 to 100% load.
Figure 2: SGT-600 DLE bypass system.

The combustion stability and emissions are kept at low levels over the load range by only two parameters, namely pilot fuel ratio (PFR) and bypass opening. No mapping is required over time since there are no parameters in the control that drift over time [4].

Today the DLE burner is the standard design for a SGT-600. The conventional combustion system is available as an option for customers whose turbines run primarily on liquid fuel.

Extension of engine life cycle

The extension of the life-cycle of the mature SGT-600 fleet has been driven by operator demands and an aging of the fleet. A significant number of the engines in the SGT-600 fleet are approaching their design life of 120,000 EOH (Equivalent Operating Hours).

The latest design modifications of SGT-600 fleet and available operating experience give Siemens the opportunity to consider the extension of the life cycle of the engine beyond 120,000 EOH (up to 180,000 EOH, dependent on the previous operation profile and history).

The scope of the life-cycle extension is strongly dependent on the engine component condition at 120,000 EOH. The engine component’s condition is determined by the engine operation profile, operation history and maintenance performed. In order to keep the life-cycle extension predictable, controllable and profitable it is necessary to know the engine history and the condition of its components before reaching 120,000 EOH, especially those components that have a long lead time. Therefore, it is recommended to have two major activities within the life-cycle extension process: a major inspection that determines the general state of the engine (Lifetime Assessment/LTA) and actual Lifetime Extension event/LTE [5, 6].
The concept of SGT-600 life-cycle extension is as follows:

- utilization of the standard SGT-600 Maintenance Plan with some extensions for LTA & LTE,
- utilization of the standard replacement intervals for hot gas path components (blades, vanes & combustor),
- LTE of the whole installation by means of extension of the lifetime of the most expensive engine parts - rotors and casings.

The developed SGT-600 life-cycle extension program is applicable for the gas turbines that are running in base load operation. The level of lifetime extension for each individual installation depends on the previous operation profile and history of this installation.

The first SGT-600 life-cycle extension was done in autumn 2007, since when 10+ life cycle extensions have been done in the SGT-600 fleet.

**Maintenance downtime reduction**

**Extension of maintenance intervals**

A Maintenance Plan (MP) with minimized downtime is strongly requested by all users and in particular by the oil & gas industry for both mechanical drive and power generation applications for onshore and offshore installations [6].

The target for SGT-600 downtime reduction was the establishment of a new MP with increased availability via planned outage hour reduction:

- extension of the maintenance intervals from 20,000 EOH to 30,000 EOH,
- reduction of downtime for the current inspections and site activities:
  - extension of shift work,
  - reduction of the Level-A inspection from 3 days to 1 day,
  - improvement of the maintenance processes and tools.

The developed MP with maintenance intervals of 30,000 EOH is initially implemented on the SGT-600 installations with base-load operation profile and latest component design.

The extension of the maintenance intervals from 20,000 to 30,000 EOH enables the operator to save two overhauls, performing three overhauls instead of five. Furthermore, the duration of the remaining inspections has been reduced. In total, for the whole life-cycle, the availability of the SGT-600 can be increased by about 1%.
Maintenance tool development to improve maintainability

Accumulated experience and analysis of performed inspections, maintenance and overhauls of the current SGT-600 fleets showed that maintainability and maintenance downtime could be further improved by developing new maintenance tools and/or modernizing the existing tools. A few examples of recently developed tools for SGT-600 maintenance activities are presented in Figure 3.

Figure 3: SGT-600 Maintenance tools: 1. compressor blade dismantling tool, 2. Gearbox tool, 3. Gas Generator extraction tool.

It was demonstrated that the just a simple compressor blade dismantling tool enables:
- reduction of compressor inspection time by 25%,
- reduction of compressor blade damage during dismantling by 80%,
- significant improvement in safety.

Maintenance cost reduction

Maintenance-cost reduction is primarily achieved via repair and refurbishment of expensive gas-turbine components. It is mainly concentrated around the hot-gas-path components, which normally require replacement on a regular basis. In some cases, in addition to maintenance cost reduction, the repairs enable the delivery time of strategic components to be shortened.

In order to make the reconditioning procedure efficient, Siemens have established reconditioning processes for a number of hot-gas-path components [6]. This enables a consistent assessment of the components going for repair and the potential for a high quality-control level on the repaired components.
The table in Figure 4 shows the maintenance plan and component replacement/reconditioning schedule for the SGT-600.

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<tr>
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<th>Level C 40' EOH</th>
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Figure 4: SGT-600 Maintenance plan and component replacement schedule.

Apart from the hot-gas-path components there are also a number of other components and areas like abradable seals, honeycombs, compressor parts, etc., that will show very different wear depending on operating conditions. The decision regarding the replacement/reconditioning of these components will be made during the overhaul of the unit and the components are then repaired on condition. These repairs are not included in the planned activity because they are difficult to forecast. As they are normally detected during an overhaul, repair will require a short turn-around time. In response to this, Siemens have increased their efforts in regionalization. To find, qualify and approve different repair shops globally has become an important and continuing activity at Siemens. Availability of the pool of repaired components also will help to avoid overhauls extension and keep maintenance cost under control.

Currently available repair capabilities for SGT-600 are presented below.

Compressor components
Compressor components are repaired on components’ condition and are not included in the standard maintenance plan.

The following reconditioning of compressor’s components can be done:
- recoating of the blades and vanes,
- recoating of the stator rings above blades (abradable coating) to restore the compressor performance,
- repair of the rotor seals,
- repair of the compressor rotor, including exchange of the compressor disks.

**Combustor**

Developed reconditioning and repair processes of the combustion chamber are included in the standard maintenance plan and consist of:

- local weld repair,
- exchange of outer and inner liners,
- weld repairs of the burners,
- TBC (Thermal Barrier Coating) recoating.

**Turbine components**

Reconditioning and repair processes for the compressor-turbine components are included in the standard maintenance plan:

- weld repair of vane 1 & 2 (latest solution),
- recoating of vane 1 & 2 (new environmentally friendly recoating technology is in use),
- repair of heat shields above blade 1 & 2 (brazing of new honeycomb),

Recently on condition repair of the Blade 1 was introduced. This repair process includes weld repair and recoating.

**Operation improvement**

To obtain individual information about the operation of each gas turbine and thus improve operation of the unit and be better prepared for coming maintenance, continuous monitoring of the gas turbine is very important. Continuous monitoring of the operation of the gas turbine and the condition of its components enables the operator to support flexible plant operation, to minimize the risk of plant malfunction or breakdown, to reduce the downtime and, finally, to reduce the plant/gas turbine life-cycle cost [7, 8].

STA-RMS – Siemens Industrial Turbomachinery Remote Monitoring System – is a remote and condition-monitoring system that has been developed for all Siemens Industrial Turbomachinery
rotating equipment (gas turbines, steam turbines and compressors) and provides a wide range of functionalities [9, 10]:

- monitoring, trending and analysis of main engine parameters (e.g. rotation speed, pressures, temperatures),
- performance monitoring and analysis,
- vibration monitoring and analysis,
- emission monitoring and analysis (for gas turbine),
- operation and maintenance optimization.

Siemens believes that operators will have many benefits from this system as it shares accumulated OEM (Original Equipment Manufacture) SGT-600 fleet knowledge and experience with the operator. The most recent development of the STA-RMS provides a powerful tool for the operator to follow up his rotating equipment, predict its future maintenance and provide a way for optimizing the rotating equipment and plant operation.

The STA-RMS concept includes the following levels:

- Level 1 - data collection on site. Data collectors have been designed for the various types of rotating equipment for industrial applications within Siemens Energy
- Level 2 - data transfer and remote access. A common Siemens cRSP (common Remote Service platform) solution has been developed and implemented.
- Level 3 - data storage in a common Siemens Energy Industrial Applications database, RMS database.
- Level 4 - data presentation in the form of graphs, KPIs (Key Performance Indicators), trends, automatic reports, automatic diagnostics, common Siemens Energy Industrial Applications RMS web interface.
- Level 5 - different plug-ins/agents or customer support services: help-desk, evaluated reporting, remote services, advanced diagnostics, risk assessment, decision support, flexible operation, condition-based maintenance.

**Ongoing SGT-600 upgrades and improvements**

Currently, a new upgrade of SGT-600 is under development with focus on further emission reduction (from 25ppm to 15 ppm NOx), flexible operation (cyclic life-time extension - doubling), power and efficiency increase at hot ambient temperature, further extension of Time Between Overhauls (from 30 000 EOH to 34 000 EOH).
Emissions

Further development has been carried out on the lean mixture principle, with a four-slot cone and an added mixing tube that will reduce the emissions further (down to 15 ppmv NOx, dry) - the 3rd generation DLE. This type of burner is already standard in the SGT-700 and SGT-800 and one installation already exists for the SGT-600.

Flexible operation

In order to respond to latest customer demands in flexible operation and movement towards the cyclic operation mode, the cyclic life of some of SGT-600 components will be extended by means of components modifications.

Conclusion

Continued enhancement of the SGT-600 fleet is part of Siemens' long-term product development strategy and has resulted thus far in:

- High reliability and availability of the SGT-600 fleet.
- Low emission combustion. SGT-600 DLE combustor technology is reliable, simple and therefore low in cost.
- Extended engine life-cycle (from 120,000 EOH up to 180,000 EOH).
- Extended maintenance intervals (from 20,000 EOH to 30,000 EOH and as a result up to 1% extra availability).
- Maintenance cost reduction.
References:

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