ABSTRACT

Siemens Energy has launched a new industrial gas turbine, the SGT-750, a twin-shaft gas turbine for both mechanical drive applications and power generation. Attaining efficiency of 40% and with a 37MW shaft output, the power and twin-shaft configuration (which allows start-up against a loaded compressor) make the SGT-750 ideal for midscale LNG or Cascade liquefaction processes. Package designs ensure suitability for all applications onshore and offshore.

The Oil & Gas industry was the prime focus for this development, with availability and serviceability being the main design considerations. Maintenance work can be performed on-site on the installed machine, or the gas generator can be exchanged within 24 hours to minimize downtime. Scheduled maintenance with gas generator exchange has been cut to a mere 17 days in 17 years on this turbine. Long service intervals and easy access for boroscope inspection all help guarantee optimized availability. Hot section blade temperature can also be monitored during operation, a ‘health check’ to ensure availability.

To ensure maximum dependability, proven technology and components from other Siemens gas turbines have been used. The burners are based on known DLE technology, and allow for operation across a wide load range with minimized NOx emissions. The dual-fuel DLE combustion system can operate on a wide range of gas fuels, and can maintain stable combustion despite rapid changes in fuel gas composition, such as increases in nitrogen content. The high exhaust energy provides for excellent overall energy efficiency when used in Cogeneration or Combined Cycle applications, resulting in low fuel consumption and reduced CO2 emissions.

This paper will describe the development and verification of the SGT-750 and the new features introduced on this model. With uptime an important factor for an operator, the special focus on this aspect during the design phase will be highlighted.

INTRODUCTION

The SGT-750 is designed to meet the oil and gas industry’s high demands for reliable, clean and efficient power equipment with state-of-the-art performance. Its design philosophy was therefore based upon simplicity, robustness and the use of proven technology, the design being based on standards used in the oil and gas industry. Other values, such as low Life Cycle Cost (LCC), plant compactness and short delivery time, have also been addressed. This heavy-duty gas turbine is designed to incorporate advantages of the aero-derivative gas turbine such as fast gas-generator change-out while at the same time maintaining the robustness, flexibility and long-life advantages of the traditional industrial gas turbine.

The SGT-750 is a twin-shaft gas turbine (figure 1) which is suitable for either mechanical drive or power generation. The high-efficiency, high-speed, 6100 rpm power turbine is well suited for mechanical drive. In power generation the free power turbine enables the SGT-750 to cope with fluctuations in the frequency of the grid, and permits both frequent and rapid starts, reaching full load in less than 10 minutes. The complete gas turbine unit is mounted on a single base frame into which the lube oil tank is integrated. All the auxiliary systems such as start motor and electrically driven back-up systems are mounted on the base frame.
The technology in the SGT-750 is based on the overall Siemens gas turbine fleet, both the industrial and the utility ranges. Development focused mainly on the core engine in order to improve performance and emissions further, while the design of auxiliary systems was to a large extent based on the SGT-600/700 package.

Since environmental performance, such as limiting NO\textsubscript{x}, CO, CO\textsubscript{2} and noise emissions, is becoming increasingly important, the high-efficiency SGT-750 has a low carbon footprint, the Dry Low Emissions (DLE) combustor being standard for low nitrogen oxide emissions.

**Installation**

The SGT-750 installation (Figure 2) meets stringent requirements for compactness, short installation and commissioning times and ease of maintenance. The gas turbine is skid-mounted, with the auxiliaries grouped in self-contained modules placed in the auxiliary room. The layout is based on the same standard for all applications, whether mechanical drive or power generation, onshore or offshore installation.

The gas turbine driver skid is built from steel beams, supporting the gas turbine, auxiliary systems and starter motor and, if applicable, speed-reduction gear. The auxiliaries are located in front of the gas turbine air intake in the auxiliary room. The gas turbine driver skid is connected to the driven equipment which can be on foundation or skid-mounted. The whole package thus forms a single-lift unit, whose benefit is faster installation on site with less work at site. The air intake and exhaust stack are supported by separate external beam structures. A two-stage static air filter is supplied as standard, but other options are also available, such as jet-pulse three-stage etc, depending on customer requirements. In the standard version, the electrical and control module containing Motor Drive System (MDS), batteries and unit control cubicles stands on its own support adjacent to the gas turbine/generator skid on the air intake side.
Gas turbine technical description

The gas turbine consists of an axial flow gas generator with a 13-stage compressor, combustor and a two-stage air-cooled compressor turbine. The two-stage uncooled power turbine is counter-rotating relative to the gas generator for higher efficiency. The higher efficiency comes from more efficient use of the outlet swirl from the gas generator.

Performance

The SGT-750 is designed to meet the very high expectations of performance with over 40% efficiency at 37 MW and market leading emissions. For different ambient temperatures there is an opportunity to select different matching on the power turbine in order to optimize performance for example the hot ambient matching gains two MW at 50 deg C compared to normal matching. Another important performance aspect is the ability to burn different types of fuels, to be fuel-flexible. In the SGT-750 Siemens has used the experience of fuel flexibility from the rest of the Siemens fleet. The SGT-750 is able to cope with large amounts of inert gases, pentane and varying wobbe index, all with maintained combustion stability.

Compressor

The compressor (figure 3) has 13 stages with a pressure ratio 24:1. Two variable guide vane rows and three compressor bleeds located after stages 3, 6 and 9 are used during start-up and part-load operation. This is a more robust design compared to multiple variable guide vanes. The configuration was chosen for maximum reliability, with highest possible compressor performance.

The compressor rotor disks and shafts are welded together by Electron-Beam (EB) welding, the same technology as used on other Siemens gas turbines. EB-welding has the advantage of low heat release to
maintain the accuracy of the disk alignment. Field-balancing possibilities are provided for, as well as access from the outside to the standard instrumentation at the bearings, which facilitates easy exchange of vibration probes if necessary. All materials have been selected to suit hot and cold ambient conditions. Protective anti-corrosion coating is also available if required, for example in offshore applications, where salt from the sea can lead to corrosion issues.

The compressor is designed using state-of-the-art design tools and proven technology originating from other recent Siemens gas turbines. All compressor blades are designed with controlled diffusion airfoils (CDA) axially attached to the rotor disks for easy maintenance. Thanks to this, compressor blades can easily be exchanged if necessary. The guide vanes are assembled as segments with inner shrouds for minimum leakage and maximum performance. All blades can easily be inspected from outside through borescope inspection holes. Furthermore, an extra split plane in the casing has been introduced after stage 2 to enhance the serviceability in the front part of the compressor.

4th generation Combustion system

The combustion system has been thoroughly tested in flow tests, atmospheric tests, pressurized tests and fuel flexibility test. The air flow pattern around the combustors has been studied both numerically and experimentally, showing a very uniform velocity- and pressure distribution, an important prerequisite for low emissions and low combustion pulsation levels.

A full scale single-burner combustion rig test was successfully conducted at real engine conditions. The maximum pressure in the tests was 28 Bar and maximum air temperature was 530 deg C. All operating conditions within the ambient temperature range from –60 deg C to +55 deg C were successfully tested.

The pressurized test confirms earlier tests and numerical analyses and gives us high confidence that the combustor system is very stable with ultra-low emission capability over the whole operating range.

The SGT-750 combustion system is a can combustor system with 8 cans (figure 4), a well established design concept in Siemens gas turbines. The design has been developed with focus on high reliability and
easy maintenance to ensure highest possible uptime. Individual combustion chambers can be replaced from the compressor side without disassembling the turbine module, thus helping to keep maintenance time down to a minimum. The dual-fuel option has DLE capability on gas. Water injection can be used to reduce NOx emission during liquid fuel operation. The system is designed for smooth switchover between liquid and gaseous fuels during operation.

**Figure 4: Combustor design**

The 4th generation DLE burner is designed for extremely low emissions over a wide operating range. A compressor discharge air bleed is available to further reduce the emissions at very low loads. Siemens technology has been used as basis for the development of the 4th generation DLE burner used in the SGT-750, and developed further with optimized aerodynamics and excellent fuel/air mixing. The expected values for NOx and CO are below 15 ppm at 15% O2.

**Compressor turbine**

The compressor turbine is a two-stage air-cooled design. The CT blades are unshrouded and rub into an abradable coating in the shroud segments for minimized over-tip leakage. The gas path at blade 1 and 2 is cylindrical for stable tip clearance during axial thermal movements in transient operation.

The compressor turbine casing is also cooled with cooling air from compressor stage 9. This reduces the temperature of the casing by 100˚C compared to full-pressure air and thus reduces thermal expansion and improves the blade tip leakage for increased efficiency.

During overhaul the compressor turbine hot section is handled as a single module for increased uptime. The module comprises the two bladed disks and the turbine stator. The disks are bolted to the rotor with 12 tie-bolts. The torque is transferred from the disks to the rotor with a curvic coupling, which has proven balancing behavior and low assembly time. The second disk has a balancing plane accessible from outside without stripping the engine.
Throughout the development of the SGT-750, design work has focused on reliability and uptime. All materials in the turbine are well proven in the Siemens gas turbine fleet. The relatively low turbine inlet temperature (TIT) areas (as a comparison, 56°C lower than SGT-800) was selected in the interest of robustness.

For high reliability, the cooling technology is based on proven in-house designs and only proven materials are used. The stage 1 vane and blade have both film and convection cooling with compressor discharge air, the same technical solution as SGT-700 and SGT-800 where it has proved to be very reliable. These blades and vanes have a thermal barrier coating for reduced cooling-air consumption. This leads to higher efficiency and lower fuel consumption. The stage-2 vane and blade are conventionally cooled with cooling air from compressor stage 9. The layout of the CT-PT (compressor turbine-power turbine) gas path is made with a minimal increase in hub radius from CT to PT. This avoids using a turbine intermediate duct and thus reduces aerodynamic duct losses, also reducing the size of the engine and the hot surfaces (see figure 5).

![Two-stage air-cooled compressor turbine](image1)

![Two-stage counter-rotating uncooled power turbine](image2)

**Figure 5: Compressor and power turbine**

**Power turbine**

The Power turbine (PT) is a free two-stage turbine that can be used as a variable-speed mechanical driver with a speed range of 50-105% (3050-6405 rpm) or for power generation at nominal speed. Blades 3 and 4 are shrouded for dynamic damping. The shrouds have two seal fins each and cover the throat area for improved efficiency.

Vane 3 (first power turbine vane) can be selected with different flow capacities optimized for normal or hot climate. By alternating the flow capacity of vane 3, the speed of the gas generator is optimized to increase performance at the dedicated site.

The exhaust diffuser structure is cast as a solid single component in a creep-resistant steel for high temperature. The diffuser and blade 4 are aerodynamically designed together for optimal total performance of blade and diffuser recovery by optimizing the pressure profile at blade 4 outlet. Not only to achieve the
highest blade performance but also to achieve highest performance for the whole system by increasing pressure recovery in the diffuser.

The power turbine inner casing hosts the rotor bearings. All essential instruments are replaceable from outside without stripping the engine, which will increase uptime. By tapering the shaft, a straight line of sight from the port holes in the rear of the engine to bearing #3 was created for reliable assembly of instruments such as vibration and temperature monitoring.

During overhaul the power turbine stages 3 and 4 are handled as a single component using a module tool with the same principle as the compressor turbine for reduced downtime.

Verification test

For the verification test a new test rig with full load capability has been built at Siemens workshop in Finspong, Sweden. The test-rig will be used for later mechanical running test of sold units and can also be used for testing of the SGT-600/700. All engines below 40 MW are tested before they leave the Siemens workshop. The test rig has a cart system for rapid exchange of engines and this has increased Siemens’ testing capability significantly.

Manufacturing and assembly of the SGT-750 started in 2011 and the first units were ready summer 2012. Two units will be used for testing. The first unit is the performance engine which will be used for setting the start sequence and performance test. This engine only has a minor extra instrumentation in order to ensure correct performance. It was started for the first time 3rd September 2012; 25th September full load was achieved and the test crew could happily conclude that the performance target was reached!

The other unit will be heavily instrumented to verify the design. This unit will have 2200 test points whereof 290 are rotating. Several measurement methods are used, for example: temperature, pressure, pulsation, strain gauge optical probes and infrared turbine blade temperature scanning. The other unit will be used to set the start sequence and for the performance test.

The first commercial unit “Greifswald” went ex-works August 2012 (see figure 6). This unit is a cogeneration application on the Nord stream pipeline at the gas-receiving station in Germany. Here, it heats the gas coming up from the pipeline and pushes it further down to the compressor station “Radeland” where three SGT-700 turbines are used for compression. The “Greifswald” turbine will enter commercial operation spring 2013. The second turbine, a 60Hz machine destined for the Americas, will be delivered during the summer of 2013.
Figure 6: Gas turbine single lift

Maintenance

There are two options available for performing maintenance on the gas generator, auxiliaries and driven equipment. An industrial type of on-site maintenance where all activities can be performed on the customer's site and an aero-engine type of off-site maintenance featuring a fast core exchange where the maintenance of the core is performed at a local workshop or at the nearest Siemens facilities. Total downtime for preventive maintenance in seventeen years of base load operation is 48 days for the on-site option and a stunning 17 days for the off-site option using an exchange engine. This ensures maximized availability and minimized risk of production loss. The maintenance plan also includes an innovative annual on-load performance inspection. This is based on remote diagnostics of operational data by Siemens specialists and does not need any downtime. This performance inspection takes place every calendar year when no A, B or C inspection is planned. Remote diagnostics are also used upfront of the inspections to determine the scope of work.

A maintenance plan is developed for the preventive maintenance during the gas turbine’s life-cycle and this includes parts replacement schemes and activities at different levels. It is designed to optimize cost and availability during the lifetime of the gas turbine. Inspection intervals are based on EOH (Equivalent Operating Hours) or EOC (Equivalent Operation Cycles), whichever comes first. Component lifetime has been optimized for long service intervals. Based on field experience from the designs in the SGT-600/700 fleet and extensive component testing, time between major overhauls for the SGT-750 could thus be extended to 68,000 Operating Hours.

The maintenance plan for the SGT-750 with corresponding inspection levels for the gas turbine is shown in Figure 7. The program contains 8 level A (boroscope), 2 level B (hot section) and 1 level C (overhaul) inspections. Various other activities such as power turbine maintenance, generator or compressor maintenance are included in the different levels. A full maintenance period is reached after 136,000 EOH, i.e. approximately 17 years of continuous operation. After a full maintenance period there will be a lifetime extension package to continue operation.
The unit has a number of features that simplify maintenance and inspection. Borescope ports are available for inspection of five of the compressor stages. At the front of the air inlet chamber, a door is fitted allowing access to the compressor. An overhead crane is installed inside the gas turbine enclosure to facilitate maintenance and enough space is available to allow operating personnel to walk around the machine. Exchange of combustor components is enabled within the enclosure.

A core engine exchange can be performed within 24 hours from load to load, which is another important feature to maintain availability in the event of a forced outage. For flexibility, the gas generator can be removed from either side (to be selected) of the installation. The gas generator is then disconnected from the air intake and power turbine and removed sideways on a rail assembly.

**On-line monitoring system for hot blades**

The SGT-750 uses high-speed on-line infrared monitoring of the hot blades. Turbine blade 1 and turbine blade 2 are equipped with 2 infrared cameras each covering the pressure side, suction side and the platforms. In figure 8 the leading edge of a blade can be seen in three pictures while it passes the camera. The information from the cameras can detect anomalies before they go to critical events. This system shows high-resolution images of rotating blades in operation, showing the actual surface temperature of the blades.

Before and after each inspection an evaluation of the surface temperature of the turbine blades in the compressor turbine is performed. The gas turbine is started and put on load and the actual material temperature of the blading is measured. This method mitigates risk due to early problem detection by detecting cracks or blockage of cooling holes.

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**Figure 7: Inspection levels and intervals**

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New and innovative way of working

Significant attention was devoted to serviceability and increased uptime. Working with 3D tools in a visualization studio made this dramatically simple. In co-operation with the University in Norrkoping, a 3D stereo visualization approach was developed and used for the complete gas turbine package, to evaluate different design alternatives from an access and service perspective. The complete gas turbine and the package were comprehensively modelled for simulation of access. All interfaces within the gas turbine and also between the core engine and the base frame with its auxiliaries were optimized. All 3D studio sessions involved designers, assembly shop representatives and service engineers to ensure that site experience is fed back to the development process.

Good serviceability must be built in to the design concepts from the very beginning. During this process different design alternatives, from inlet to outlet, were evaluated for better access and all foreseen service situations were simulated to reduce service time. As a result the location of many components and the design of many features have been improved from an assembly, access and service perspective.

CONCLUSION

The SGT-750 is able to meet the oil & gas industry’s demands for efficient and clean power based on gas turbines offering a high level of performance without sacrificing reliability. New design tools have been used to increase reliability and as a result the SGT-750 has the highest uptime on the market. The design of the SGT-750 has ensured that it has a very low life-cycle cost and that it is suitable for a wide range of applications, features which are in line with current and future customer requirements, for example both on-site and off-site maintenance can be applied and the gas generator can be exchanged within 24 hours. The first SGT-750 has been tested and both power and efficiency have been confirmed.