Siemens H: uprate and commercial release follow design validation

Update on the Siemens SGT5-8000H, currently the world's largest gas turbine

Reprint from
Modern Power Systems, September 2009

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Willibald Fischer and Steven Abens, Siemens, Erlangen, Germany

Following extensive design and product testing and validation at Irsching the key performance parameters of the SGT5-8000H gas turbine have been found to meet or even exceed expectations. Based on careful evaluation of test data and comparison with design predictions, we have uprated the machine as follows:

<table>
<thead>
<tr>
<th></th>
<th>SGT5-8000H (simple cycle)</th>
<th>SCC5-8000H 1S (single shaft combined cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introductory rating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>340 MW</td>
<td>530 MW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>39%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td><strong>New rating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>375 MW</td>
<td>570 MW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>40%</td>
<td>&gt;60%</td>
</tr>
</tbody>
</table>

Based on the positive experience resulting from the 18 month test phase at Irsching 4, Siemens is now in a position to offer the 8000H system to the power generation market for commercial applications.

This is the culmination of a programme that started nine years ago, with the following milestones, all achieved on time:

- Programme Launch - Concept Phase October 2000
- Gate 1: Product Strategy March 2001
- Gate 2: Start Basic Design (GT) November 2001
- Gate 3: Product Release (GT) August 2004
- 1st engine shipment, from Berlin April 2007
- 1st fire at Irsching 4 test centre December 2007
- 1st synchronisation to grid March 2008
- 1st achievement of baseload power April 2008
- End of test & validation phase Summer of 2009
- Gate 4: Commercial release 2009

A remarkable feature of the programme to date is that Full Speed Full Load was achieved a mere nine operating days after synchronisation, with the first-build version of the engine. Also, right from the first start ignition has been stable and reliable.

The engine has been recognised by the Guinness Book of Records as the “largest functioning gas turbine.”

Validation process

To minimise the risks associated with introducing new technology, in particular advanced gas turbines, comprehensive test and validation has been central to the SGT5-8000H programme. This has included tests on prototype parts during the design phase, followed by sub-system validation such as atmospheric and high pressure combustion testing, as well as full-scale, 60 Hz compressor validation.

The individual component, sub-system and then engine tests were performed in the Siemens Berlin test centre and at several other test facilities.

Key parameters, such as the compressor pressure ratio and aerodynamic efficiency, temperatures of hot gas path parts, characteristics of combustion dynamics, engine output, vibration and emissions, were validated and demonstrated.

But the crucial phase of validation is engine operation under real power plant conditions. Preparation for this phase started as early as 2005 with the installation of about 3000 sensors in and on the prototype engine during manufacture. In addition to the standard instrumentation associated with the normal gas turbine I&C system, these sensors measure temperatures, pressures, strains, flows, acceleration, and vibrations encountered during part load and base load operation and enable engineers to compare the design models with the actual engine response. Two telemetry systems, located at the turbine bearing as well as the intermediate shaft at the compressor end, delivered some 600 additional signals from the rotor.

The partner for this extensive validation project was E.ON Kraftwerke, under a unique contract negotiated to give Siemens maximum flexibility in testing the new gas turbine, while enabling E.ON to add the world’s first combined cycle plant with 60% efficiency to its fleet.

The Irsching power plant site was selected for this common project due to its existing infrastructure and location within the HV grid. The contract defines two stages. During the first stage, Siemens built a gas turbine power plant in a simple cycle configuration and operated this plant for 18 months for testing purposes under the terms of a hosting agreement.

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For the first stage the following configuration was adopted:
- single shaft arrangement, with provision for addition of a steam turbine connected the single generator;
- water cooled generator (SGEN5-3000W)
- temporary exhaust stack;
- fuel gas supply connection to the E.ON Ruhrgas pipeline and fuel transfer station;
- auxiliary systems for gas turbine and generator;
unit transformer connected to the E.ON grid;  
• electrical auxiliary power supply, MV and LV switchgear and I&C systems;  
• test and control centre for plant operation; and  
• turbine building with large capacity cranes.  

Preparations for civil works on the foundations started in mid 2006 and initial steelwork started in January 2007.  

The second phase of the contract, which started after completion of the 18 month test phase and demonstration of the contractually defined performance of the gas turbine, requires the extension of the simple cycle configuration to a single shaft combined cycle power plant. This is to be commissioned and handed over to the customer as under the terms of a “standard” EPC arrangement.  

To operate the gas turbine during the 18 month test period, additional contracts, with the gas provider and for the sale of electricity, were implemented. The gas contract did not stipulate any minimum gas consumption. The electricity sales contract covered any power which was produced by operation of the gas turbine. Both these contractual arrangements allowed maximum testing flexibility for validation of the gas turbine (without such constraints as a commercial availability guarantee).  

The prototype engine was shipped from the Siemens gas turbine manufacturing plant in Berlin at the end of April 2007 and was placed on the foundation at the Irsching 4 site at the end of May 2007.  

During engine installation, a considerable quantity of additional instrumentation, such as externally-mounted blade vibration sensors, pyrometers, tip clearance and flow field probes as well as two infrared turbine blade monitoring cameras, was installed.  

Concurrent with erection of the power plant, test facilities including the extensive data acquisition system (DAS) were added. The DAS set-up was not limited to the Irsching site. A dedicated encrypted data network connecting the Irsching test centre and the engineering headquarters in Muelheim, Germany, and Orlando, Florida, was established. This network enabled 100 additional engineers to have a live view of engine operation without the need for on-site presence and contributed to both testing operations as well as engine safety.  

Cold commissioning of the gas turbine was successfully completed in December 2007. The four-phase structured testing operation was commenced with the successful first fire, on 20 December 2007.  

First test phase. The first test phase was mainly driven by auxiliary and start-up commissioning steps, with optimization of start-up and protection settings. Mandatory full speed no load (FSNL) tests such as speed sweeps for validation of compressor and turbine blade eigenfrequencies and generator protection trials were also conducted. Test phase 1 ended with first grid synchronisation, on 7 March 2008.  

Second test phase. Test phase 2 included the first loading to full speed full load (FSFL) and all related tests for optimising the loading schedule for the Irsching 4 schedule. First build was the version as manufactured in 2005/2006. The second build included improved components in some areas of the hot gas path, in particular with the aim of reducing cooling air requirements. Final build is the version identified during the test phase as the configuration for commercial application.
five fuel gas stages of the combustion system as well as the four stages of variable guide vanes. Test phase 2 culminated in achieving baseload (full power) for the first time, on 24 April 2008.

Third test phase. The primary focus of test phase 3 was mapping of aerodynamic and thermodynamic performance at part load and baseload as well as final combustion tuning to meet emissions requirements. Test phase 3 also included tests with preheated fuel at various loading rates and also load rejection tests. Pyrometers were utilised to gain a more comprehensive picture of surface temperatures of the rotating turbine parts. Flow probes were installed in the diffuser and in the turbine flow path to determine the flow fields.

The third test phase also included a comprehensive thermal paint test, which uses temperature-indicating paints to give a permanent visual record of the temperature variations over the surface of components. Thermal paints do not modify the thermal behaviour of a component during testing and can be applied to surfaces with small-diameter cooling holes without affecting the cooling effectiveness. But thermal paint tests entail a significant investment in terms of testing time and financial expenditure.

For the Irsching 4 paint test, two extensive outages were required. During the first 8-week outage, several components coated with the thermal paint were installed in the combustion and turbine sections.

On 30 January 2009, the engine was restarted and loaded directly to baseload for 10 minutes of operation. Precise timing of the operating sequence was essential to produce representative results. Overall, the test run itself only took one hour. Subsequently, the unit was shut down to remove the painted parts during the second outage, which lasted another six weeks.

In the subsequent months, the thermal paint colour changes were evaluated and very valuable temperature profiles over the entire surface of the hot gas path parts determined.

At the end of test phase 3, in April 2009, the engine had accumulated 300 operating hours. The mortality rate of the prototype sensors was comparatively low and thus terabytes of very valuable data were recorded and will be used for further evaluations in the future. Having completed test phases 1-3, all specific operational tests were successfully concluded. During these 15 months of testing, frequent inspections were conducted and valuable service and outage experience was also gained. For example, the overall effort involved in the thermal paint test described above is comparable to the effort required for an extended hot gas path inspection.

The “second-build outage” was completed on schedule, providing in the field verification of the “roll-in/roll-out” concept for the turbine vane carrier.
The experience with outages also provided in-field validation of the roll-in/roll-out concept for the turbine vane carrier, which enables exchange of stationary turbine hardware without rotor lift during hot gas path inspections. Use of hydraulically tensioned bolts at joints further contributes to reduced outage times.

**Fourth test phase.** This is the so-called “endurance test”, with the following main goals:

- amassing of further operating experience, including starts and operating hours under semi-commercial conditions;
- confirmation of “readiness for commercial service”, based on the load regime required by grid operators (grid code compliance, primary frequency response operation, grid sustaining mode (BLOC), fast start-up mode);
- operation by staff without special qualification (other than standard gas turbine O&M experience); and
- continued recording of data from the test sensor (although the prime focus is no longer on testing).

When this test phase was completed in the summer of 2009, the engine had logged operating experience equivalent to 200 starts and 3000 operating hours. This clearly completes a success story for gas turbine validation.

**SGT5-8000H - the main design features summarised**

The fully-air-cooled Siemens H class gas turbine is the first new frame developed since the merger of Siemens and Westinghouse, aiming to take the best features of the two companies’ established product lines (broadly speaking, the Siemens rotor and Westinghouse can annular burner and compressor) and combine them with advanced but proven technologies. “Design for Six Sigma” tools were applied rigorously.

Primary targets of the 8000H programme, driven by liberalisation of energy markets and the need to accommodate an increasing proportion of renewables on the grid, were:

- increased combined-cycle net efficiency to over 60%;
- reduced emissions per kWh produced;
- achievement of high efficiency and low emissions at part-load;
- fast start-up capability and operational flexibility;
- reduced investment costs per kW; and
- high reliability and availability.

The ultimate end result: minimum life cycle costs.

Air cooling, without any steam cooled parts, was selected as the basic concept because of the high degree of operational flexibility it offers – an essential prerequisite in the deregulated power generation market environment.

The key design features of the SGT5-8000H machine can be summarised as follows:

- single tie-bolt rotor comprising individual compressor and turbine disks with Hirth facial serrations;
- hydraulic clearance optimisation (HCO);
- axial 13 stage compressor with high mass flow, high component efficiency, controlled diffusion airfoils (CDA) in the front stages and high performance airfoils (HPA) in the rear stages, variable guide vanes and cantilevered vanes;
- high-temperature, air-cooled, can annular combustion system;
- four-stage turbine section, completely air-cooled; and
- advanced, on-board variable dilution air system, with no external cooling system.

A 60 Hz version of the gas turbine (12 burners instead of 16) is now being elaborated using a direct aerodynamic scaling approach, thereby minimising operational risks.

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**Table of main data for the Siemens H class gas turbine**

<table>
<thead>
<tr>
<th>SGT5-8000H (50Hz gas turbine)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Gross power output</td>
<td>375 MW</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>19.2</td>
</tr>
<tr>
<td>Exhaust temp</td>
<td>625°C</td>
</tr>
<tr>
<td>Exhaust mass flow</td>
<td>820 kg/s</td>
</tr>
<tr>
<td>Turn down</td>
<td>50%</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>25 ppm</td>
</tr>
<tr>
<td>CO emissions</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Weight</td>
<td>440 t</td>
</tr>
<tr>
<td>Length</td>
<td>13.2 m</td>
</tr>
<tr>
<td>Height</td>
<td>5 m</td>
</tr>
<tr>
<td>Width</td>
<td>5 m</td>
</tr>
</tbody>
</table>

**SCCS-8000H 1S (50Hz single shaft combined cycle plant)**

| Net power output           | 570 MW |
| Net efficiency             | 60%    |
| Net heat rate              | 6000 kJ/kWh |
| HRSG                       | three-pressure, reheat |
| HP steam conditions        | 170 bar/600°C |
| IP steam conditions        | 35 bar/600°C |
| LP steam conditions        | 5 bar/300°C |

Additional features:
- daily start/shut-down capability, high baseload and part-load efficiency,
- Benson HRSG, speed controlled boiler feed pump.
Conversion to combined cycle

After completion of test phase 4, during which the gas turbine was in simple-cycle operation, the Irsching 4 plant is now being converted into a single-shaft combined cycle power plant. To make full use of the high mass flow and exhaust temperature of the new H class gas turbine the combined cycle will employ an advanced, high efficiency, high pressure and high temperature process. This will include a Benson HRSG to be designed and supplied by Siemens, which in 2007 acquired the heat recovery steam generator business of Balcke-Duerr. Features of the HRSG will include: classical 3-pressure/reheat configuration; horizontal exhaust gas flow; cold casing; Benson HP, drum type IP/LP; HP + HP RH water injection; and special alloys in HP SH and RH to cater for advanced CCGT steam conditions. The temporary exhaust stack plus test facilities will be removed and the following components installed: SST5-3000 steam turbine and condenser; water/steam pipework and associated systems; HRSG; cooling system; and electrical and I&C systems for the combined cycle plant, including control room (with tie-in to the control room being installed for Irsching 5). The steam turbine will use a combined HP/IP casing, 600°C / 170 bar HP steam, 2 x 16 m² double flow LP with 56 in titanium last stage blade, and lateral condenser arrangement. Takeover by E.ON Kraftwerke and subsequent commercial operation of the new combined cycle plant are scheduled for 2011.

Previous articles in Modern Power Systems:
Building the world’s largest gas turbine. Germany Supplement, October 2006
SGT5-8000H - on its way to breaking the 60% barrier. September 2007
Siemens H achieves full power. May 2008

Steam turbine to be used at Irsching 4: combined HP/IP casing, 600°C / 170 bar, 16 m² double flow LP, 56in LSB (shown right)

Excavation for the HRSG foundations gets underway (August 2009)