SCC5-8000H 1S Irsching 4 on the way to 60% World Record

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Answers for energy.

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Abstract

The new SGT5-8000H gas turbine and its first implementation into a Combined Cycle Power Plant are the result of years of long standing commitment in terms of significant R&D spending and manpower resources within Siemens Energy.

Customer needs and benefits were the main drivers for the development of the new engine and power plant engineering. The focus was on increased efficiency, as well as operational flexibility. Already at the very beginning it was clear to the development team at Siemens, that this could only be achieved by a joint development effort for the gas turbine, the power train and the surrounding water steam cycle.

The 8000H program started in 2000, and after thorough development and engineering the successful component testing paved the way to the first field installation in simple cycle configuration in a real power plant environment. Siemens gained E.ON to partner for the installation of the first SGT5-8000H power plant at Irsching 4 Power Plant, Germany.

Since then the project reached one milestone after the other: First synchronization to the grid occurred on March 7, base load was achieved April 24, 2008, field validation program was successfully completed in August 2009, after over one and a half years in simple cycle operation.

The performance of the SGT5-8000H exceeded the expectations and consequently the engine, rated at 375 MW@ ISO, was released to the market. It is the largest operating gas turbine in the world, as noted by the Guinness Book of World Records. The 50 and 60 Hz versions offer high efficiency and low emissions in base load and part load. The engines are fully air cooled, resulting in the ability to start fast and cycle quickly in combination with advancements on the plant and balance of plant side, such as using the once-through Benson® type HRSG, these result in unprecedented operational flexibility.

After GT field validation was completed in August 2009, at Irsching the extension and conversion to a combined cycle power plant commenced and was completed on schedule in December 2010.

In the meantime the hot commissioning of the combined cycle is mostly finished, and everything is put in place to demonstrate the world record efficiency of 60% in combined cycle operation in reality.

As of today the engine has accumulated more than 2.500 hours of operation and more than 215 starts, during GT field testing and combined cycle commissioning.

In the first half of 2011 it is planned that the SCC5-8000H 1S Power Plant at Irsching 4 site will pass the performance test and start the reliability run together with E.ON leading to commercial operation and hand over later this year. It is expected that at the time of the presentation of this paper at the conference in June 2011, the initial key results of combined cycle operation will be available for communication.

Introduction

The worldwide need for energy is constantly rising leading to an increasing demand for reliable, affordable, efficient as well as environmentally-compatible power generation. In today's highly competitive business environment, customers and power plant operators expect an economical, state-of-the-art product. Their purchasing decisions place more and more emphasis on life-cycle cost and operating flexibility.

Siemens Energy developed its new generation H-class Siemens gas turbine (SGT™), the SGT-8000H series (Fig.1), taking both environmental protection as well as economical focus into consideration. Technical innovations in design and development, process engineering, materials and manufacturing as well as assembly processes collectively support Siemens Energy in continually transforming these new requirements into reality.

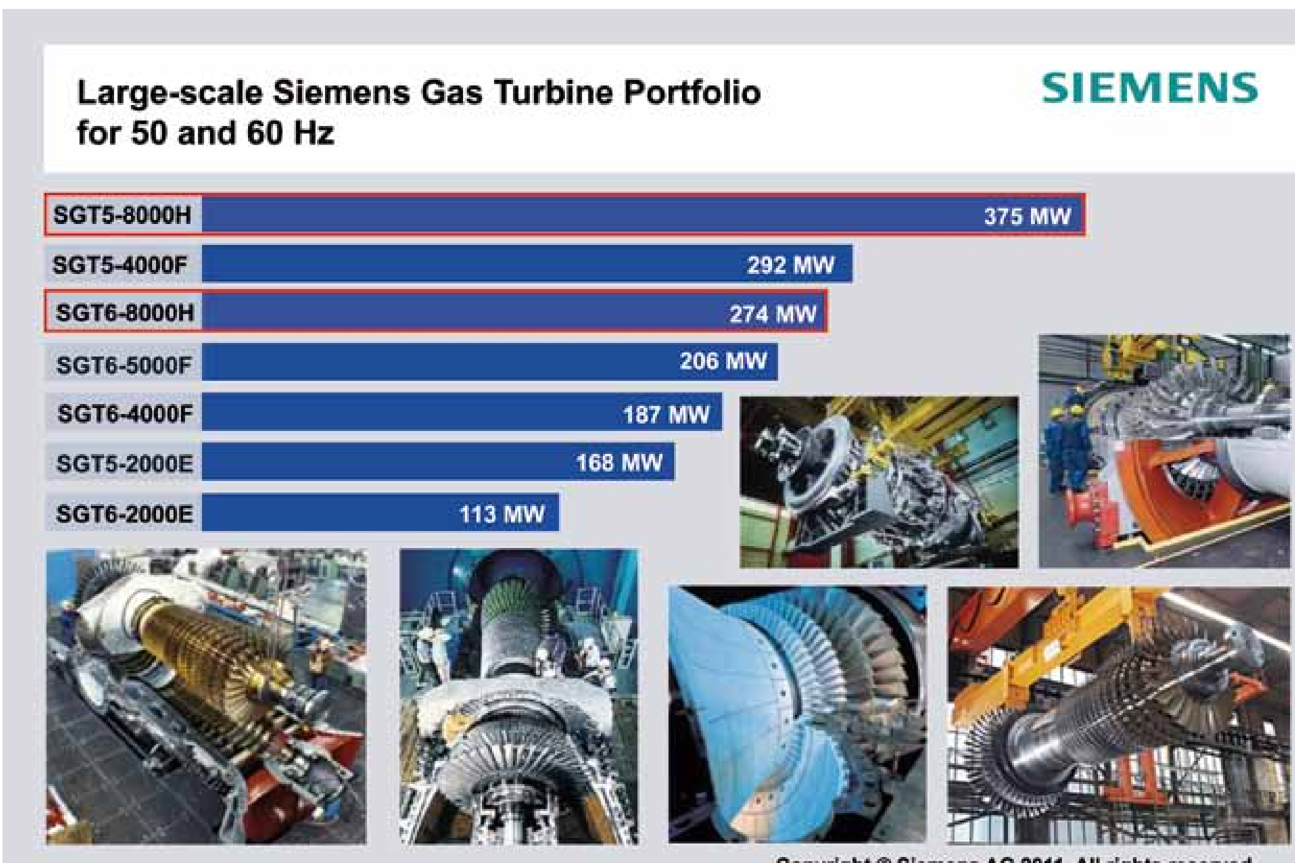

Fig. 1

Primary Targets of the 8000H Program

Customer requirements resulting especially from today's liberalized energy markets and the increased importance of balancing the increased market penetration of renewable power, were the essential drivers for developing the new SGT5-8000H. Over the ten years of the 8000H program from 2000 until today, priorities for customers have changed in some areas and require continuous monitoring of the entire energy landscape, market development and regional boundary conditions. Overall, the following key drivers were identified as basis for program success:

Product Performance:
- increase of combined-cycle net efficiency to over 60%
- increase of combined cycle output beyond 550 MW per single unit (in 50 Hz)

Maintain or Increase Operational Flexibility
- high efficiency also in part-load operation
- rapid start-up capability and increased ramp rates for fast load following ability
- turn down capability

Reduced emissions per kWh produced

Attractive CAPEX and OPEX
- lower specific investment (EUR/kW) resulting from economies of scale
- no compromises for reliability and availability

In summary ultimately resulting in lowest life cycle costs for maximized IRR and NPV.

Major Milestones of the 8000H Program and the Irsching 4 Project

Consequent program management is essential for successful execution and on-time completion of large, complex and long lasting projects like this. With appropriate methods and processes in place, all major milestones during the entire project execution period were achieved on time, a selection of the most important ones is found below:

Launch – 8000H Program	Oct. 2000
EPC Contract E.ON & Siemens Energy	Nov. 2005
Irsching 4, Phase I	
Ground breaking for civil works at Irsching 4 site	Sept. 2006
SGT5-8000H engine shipped ex Works Berlin	Apr. 2007
1st Fire Simple Cycle at Irsching 4 Test Center	Dec. 2007
End of GT Test & Validation Phase	Aug. 2009
Irsching 4, Phase II	
Completion of construction phase CC extension	Dec. 2010
1st re-synchronization to grid in CC	Jan. 2011
1st base load in combined cycle mode	Feb. 2011
Planned completion of CC commissioning and reliability run	July 2011

SGT5-8000H Design Features

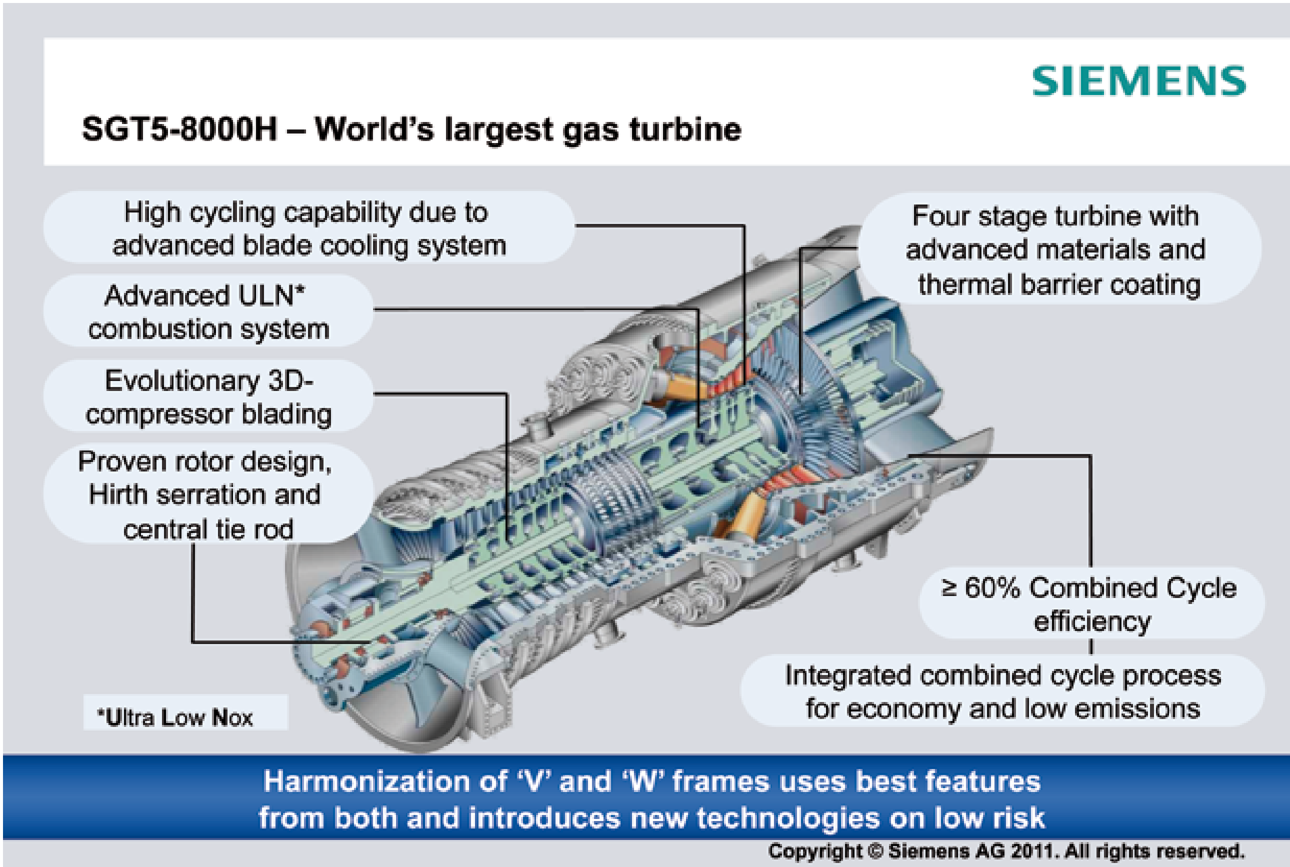

Fig. 2

The air-cooled 8000H-technology gas turbine is a 1500°C-class design with 800 kg/sec inlet mass flow and 625°C exhaust gas temperature (Fig. 2).

It is designed for low-emissions, fast start-up operation in both simple and combined cycle modes of power generation. Introductory ratings are:

- **Simple cycle**, rated at 375,000 kW base load output and 40% efficiency at ISO conditions (15°C, 60% rel. humidity and 1.013 mbar), at present, the world's largest gas turbine.
- **Combined cycle**, rated at 570,000 kW net output and over 60% efficiency which represents currently the world's largest gas fired single shaft unit.
- **Emissions**, 25 ppm NOx emissions or less at gas turbine base load output with CO emissions of 10 ppm or less.

Detailed engine design was kicked off in 2003 following intensive basic design considerations, i.e. combustion technology and cooling methods to be selected.

Engine design features include a single tie-bolt rotor with compressor and turbine disks and hydraulic clearance optimization (HCO), an advanced sealing system for low leakage of cooling air.

Turbine blades and vanes use existing base materials combined with advanced film cooling and thermal barrier coating systems to reflect the increase in turbine inlet and exhaust temperature, although the 1500°C temperature level is not new ground for Siemens, since it represents the level which is being used in the former SGT6-6000G, with 22 units in operation since early 2000.

Air cooled technology
The key feature of the Siemens 8000H technology is the application of on-board air cooling (rather than steam), insuring that cooling is always available to the hot gas path components without dependency on external systems or interfaces to the HRSG or water steam cycle of the plant to support cooling.

The air cooling system is based upon proven pre-swirler technologies, in which cooling air is extracted at appropriate levels in the compressor for highest efficiency.

This cooling air stream is then routed through stationary pre-swirlers which aligns the flow to the rotating components before being brought onboard to the turbine blades. This pre-swirling effect drops the temperature of the cooling air relative to the first-stage blades by about 50 °C. For further details please refer to [9].

This unique cooling technology is the basis for the increased 8000H performance and operational flexibility, i.e. fast start-up, shut-down and rapid load change capability.

Compressor and turbine
The compressor for the SGT5-8000H has 13 stages, with the pressure ratio of 19.2 to 1 selected to achieve an exhaust temperature of 625°C, in order to reach a steam temperature of 600°C in the HRSG. Following the proven design of the existing Siemens fleet, the compressor features vane carriers from stage 6 onwards for the respective stage groups, separated by outer bleeds.

Combustion system
While a scaling concept was used for the design of the SGT5-8000H and SGT6-8000H turbine and compressor, a different approach was taken for the combustion system.

The 50 Hz turbine features the new "platform combustion system" with sixteen can-annular type combustors. The 60 Hz engine uses the same combustion system but has only twelve combustors. The natural gas combustion system has five fuel stages (two of which are pilots for ignition and to control combustion stability) for flexible tuning capability over the whole range of engine operating conditions from ignition and idling on up to part load and full base load output. In addition, the combustion system is designed to operate over a wide range of fuel quality and preheat temperatures. Currently, emissions are 25 ppm NOx at base load and 10 ppm CO or less.

The Irsching 4 Project

Right from the beginning of the 8000H program, it was evident, that the 375 MW Gas Turbine could not be tested at full load at Siemens Berlin Test facility, which was restricted to 220 MW for various reasons at that time.

Therefore it was decided to explore options with potential partners for a joint gas fired combined cycle project, based on a schedule allowing gas turbine validation in a real plant environment with grid connection, i.e. allowing full load operation while feeding the generated power to the grid in order to compensate at least a portion of the huge operation and testing expenses.

The right partner to team up with for this challenging project was E.ON, a major German electricity provider with a variety of plants in different countries.

After a one and a half year feasibility study, during which several potential sites were investigated in terms of their suitability, the joint decision was made to select the existing Irsching site for the project (Fig. 3), located on the south bank of the Danube River near Ingolstadt, in Bavaria.

The Irsching power plant site was selected due to its existing infrastructure and location within the HV grid, in order to provide additional generation capacity in the southern part of Germany as compensation for the significant capacity of wind power installed in Northern parts of Germany during the past years.

At Irsching, E.ON had plans to modernize its power station, built in the late 1960s/ early 1970s featuring three gas-fired (originally oil-fired) units. Irsching 1 and 2 are now taken off from the grid, while Irsching 3 is still used for peak load operation.

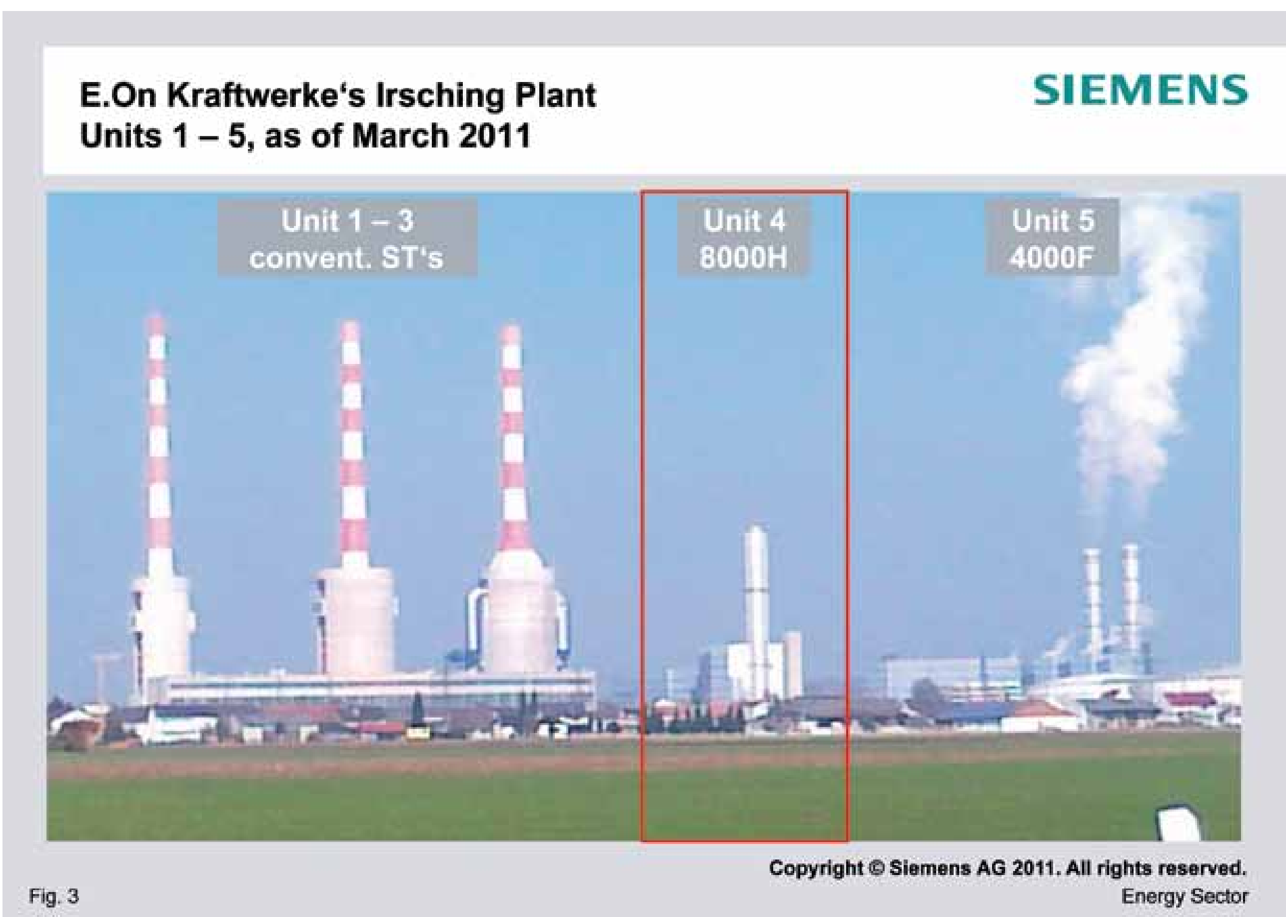

Fig. 3

To add the advanced generation unit 4, a unique contract was negotiated and structured in two phases along with the terms of a turnkey EPC arrangement:

Phase I
called for construction of the simple cycle portion of the plant, to provide Siemens maximum flexibility during the 18 months of testing the new gas turbine under the terms of additional hosting agreements for fuel supply and electricity take-off and trading.

Phase II
became active upon successful completion of the Gas Turbine Field Validation phase and required Siemens to extend the open cycle plant to a full combined cycle in single shaft configuration, by adding a HRSG, the steam turbine, cooling water systems and associated BoP, to finally add the world's first combined cycle power plant with 60+% efficiency to E.ON fleet of power plants (Fig. 4).

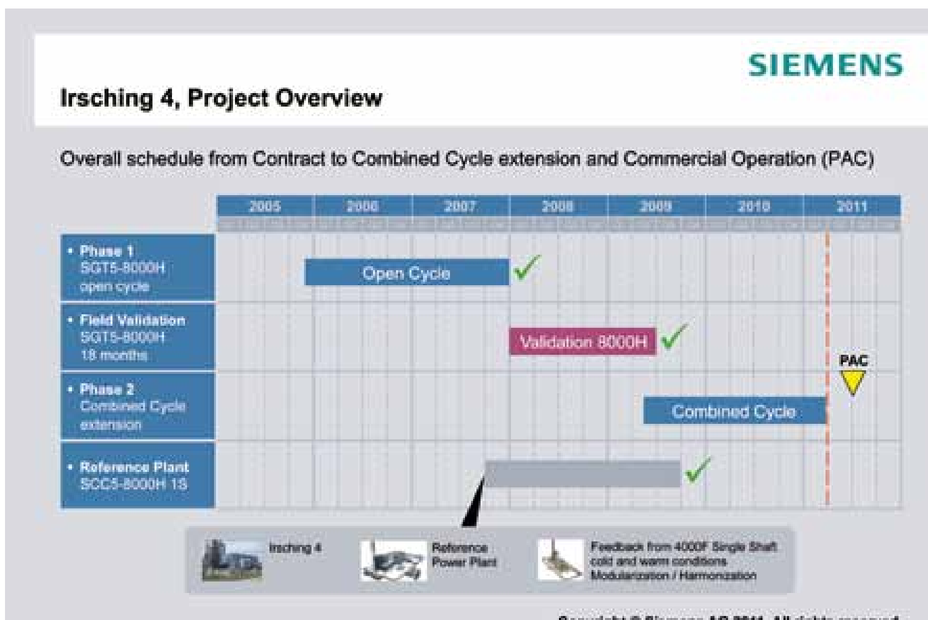

Fig. 4

Accordingly, site preparation started in 2005 and civil works commenced in 2006 with construction of the turbine foundation and structures for the main turbine building.

Whilst civil works for Phase I of the plant were nearly completed, the first SGT5-8000H engine was shipped from the Siemens gas turbine manufacturing plant in Berlin at the end of April 2007. After arrival it was placed on the foundation at the Irsching 4 site at the end of May 2007.

During engine installation, a considerable scope 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 were installed.

Cold commissioning of the gas turbine was successfully completed in December 2007 and first fire successfully celebrated in presence of several hundreds guests on December 20, 2007. Details of the following Field Validation phase can be found in [9, 11, 12]. The gas turbine test phase was successfully completed in August 2009. At the end of testing the engine had logged operating experience equivalent to 160 starts and 1500 operating hours.

Plant Design

Based on the SGT5-8000H as prime mover, the single shaft combined cycle SCC5-8000H 1S and its components are designed for 570 MW (Fig. 5).

An overall and integrated design approach was followed in order to increase plant performance from today's levels to 60% el. efficiency (Fig. 6)

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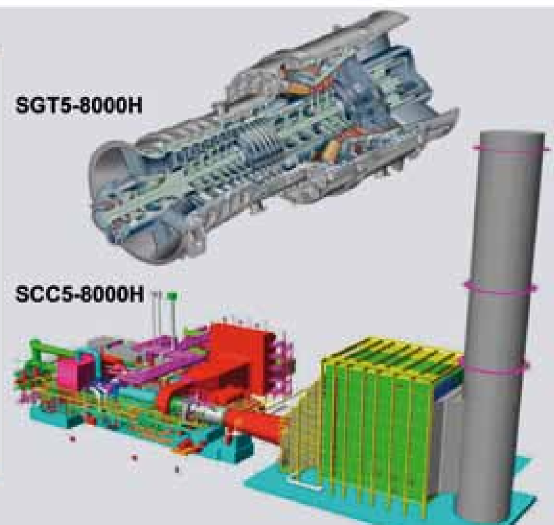
SGT5-8000H / SCC5-8000H, Key Data

Fuel	Nat. gas, #2
GT output	375 MW
CC outputnet	570 MW
CC efficiencynet	60%
Pressure ratio	19.2 : 1
Exhaust mass flow	820 kg/s
Exhaust temperature	625 °C
Turn down	50%
HRSG/WS-Cycle	600°C/170 bar Benson

at ISO conditions



Energy Sector

Fig. 5

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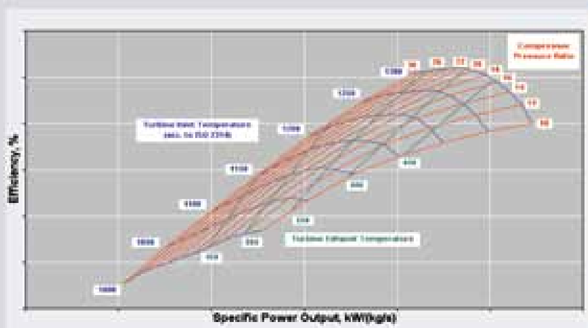
SGT5-8000H / SCC5-8000H
Significant Increase of CC Efficiency



- Increased PR + 0,2 %
- Increased TIT combined with cooling air reduction + 0,8 %
- Improved component efficiencies + 0,2 %
- Fuel Preheating of 215°C + 0,1 %
- Advanced water/steam cycle (600°C & 171 bar) + 0,4 %

Siemens H-class significantly increases efficiency by ~ 1,7%-pts. in combined cycle without compromising plant flexibility

Energy Sector

Fig. 6

The main lever to achieve higher efficiency was increasing the steam parameters from the typical 560°C / 120 bar to the new level of 600°C / 170 bar. This design target was followed through consequently starting with research and feasibility studies in 2005, followed by basic and detail design until start of erection at Irsching site in autumn 2009.

It quickly became evident that the higher steam parameters have influence on design boundaries, material selection, component sizing, plant layout, fabrication and influences all further steps into erection, commissioning and operation of the power plant.

To fulfill the higher process requirements (pressure and temperature) in the water steam cycle materials from Steam Power Plant design were implemented to a much greater degree than they have so far. Some of the materials were even applied for the first time in gas fired power plants.

Amongst others the following differences to conventional CCPP design should be noted:

- higher material quality for HRSG
- higher material quality for piping
- higher material quality for high pressure steam turbine
- bigger dimensions of several components

To give an example for the step-up in dimensions that was necessary: The overall tonnage of the HRSG increased by 55% and heating surface by 45%.

All these design evolutions became necessary to make full use of the high mass flow and exhaust temperature of the new 8000H gas turbine.

In brief the SCC5-8000H 1S comprises the following major equipment:

- Main turbine building with large 2 x 250 tons capacity overhead cranes for maintenance and housing
- Gas turbine, SGT5-8000H
- One steam turbine, SST5-5000 series, comprising of one combined HP/IP casing for 600 °C / 170 bar main steam and one double-flow low-pressure casing with 56’ titanium last stage blade for 2 x 16 m^2 exhaust area
- The associated single side lateral condenser is directly cooled with water from the nearby river
- One common, SGen5-3000W, hydrogen-cooled generator with water cooled stator frame for the steam & gas turbines
- A synchronous self shifting clutch (SSS), located between the generator and the steam turbine. It allows a self-contained individual turning mode of the gas turbine and the steam turbine, allowing faster start-up of the plant and increasing operational flexibility
- One heat recovery steam generator (once-through Benson® type in the HP section) with natural circulation; triple stage in-house designed and supplied by Siemens, through the heat recovery steam generator business, acquired from Balcke-Duerr in 2007. Features of the HRSG will include classica 3-pressure/reheat configuration, horizontal exhaust gas flow, 4 modules wide and cold casing
- For redundancy reason the water steam cycle is furnished with 2 x 100% condensate pumps and 2 x 100% feed-water pumps.
  The feed-water pumps are equipped with variable speed drives
- Mechanical auxiliaries include a condensate polishing plant with regeneration unit
- DCS plant control system (SPPA-T3000), with the O&M stations located in a joint central control rom for unit 3, 4 and 5 of the Irsching plant

- Main step-up unit transformer connected to the 380 kV high voltage grid
- Associated auxiliary equipment Balance of Plant), e.g. fuel gas receiving station, connected to the E.ON Ruhrgas pipeline, fuel ransfer and preheating station
- Electrical equipment, such as MV and LV switchgear

The scope defined in the terms of the EPC contract with E.ON covered engineering, procurement, construction, erection, commissioning and operator training on a full turnkey basis for above mentioned euipment.

Meanwhile, the Irsching 4 plant has been converted into a single-shaft combined cycle power plant and hot commissioning is almost finished in preparation of commercial operation. Takeover of the plant by E.ON is scheduled for July 2011 (Fig. 7, 8, 9). Hence the 60+% combined cycle efficiency will be demonstrated in reality and the new world record efficiency will shift existing borderlines.

Fig. 7

Fig. 9

Fig. 8

Major Milestones and Results of the Combined Cycle Commissioning and Validation Tests, Phase II

First fire in combined cycle mode was achieved early January 2011 and the first synchronization to the national grid occurred only 5 days later. The first combined cycle Base Load was achieved late February and the German grid code tests were completed end of March 2011.

During the month of March and April 2011 extensive Combined Cycle testing and optimization was carried out to validate the design. The tests carried out included:

- start-up/ shut-down tests
- load ramps
- part load optimization
- steam turbine validation
- HRSG and Benson® operation mode optimization
- additional GRID code testing

While testing is still ongoing and the detailed analysis of the results is not finished yet, it is already apparent that the field experience showed the design targets have been transformed into reality or have even been exceeded.

Especially on the fast start up the SCC-8000H series will set a new benchmark below 30 minutes for the "Hot start on the fly" (Fig. 10).

With E.ON it was agreed that several long term measuring programs will stay online long into commercial operation to gain more experience with the new configuration and facilitate further improvements.

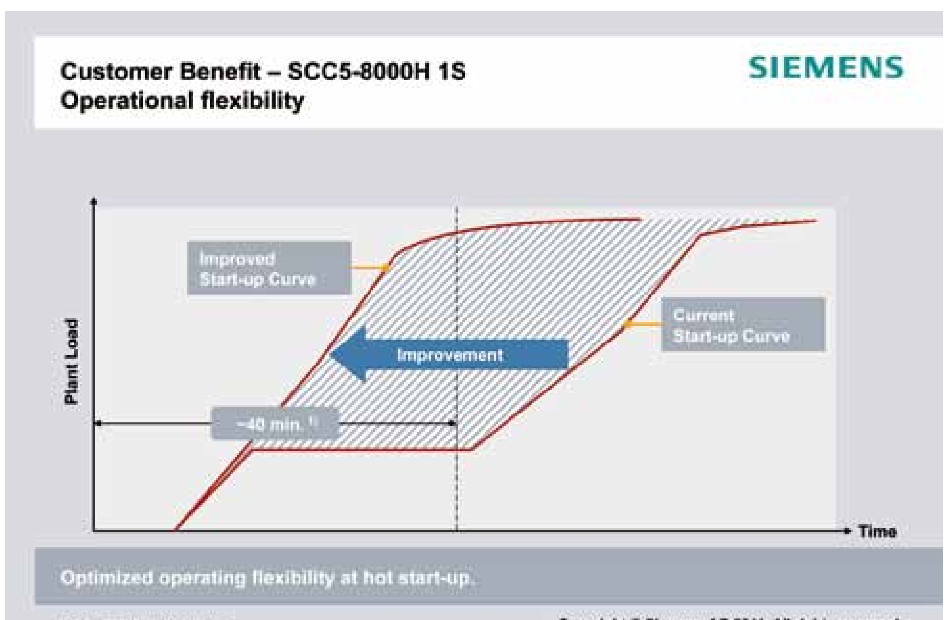


Fig. 10

The result of the testing was expressed by the customer of the first SGT5-8000H as follows:

"In actual operation, the SGT5-8000H has more than met our high expectations: During roughly 1,200 hours of testing in Irsching, Block 4, we were able to experience the performance of the world's most efficient gas turbine for ourselves. Expansion is currently underway to a combined cycle power plant. With its commissioning in the year 2011, it will similarly set new standards when it comes to efficiency and output"

Dr. Bernhard Fischer, Member of the Board of Management E.ON Energie AG, Germany

Market Launch, Commercial Projects

First commercial customer projects like the 1200 MW Cape Canaveral and Riviera Clean Energy Centers of Florida Power & Light or the 410 MW unit Bugok III of GS EPS (GS Electric Power & Services, Ltd.,), Seoul represent the market introduction phase, with currently eight units in total. These projects are based on the 60 Hz version of the 8000H.

The SGT6-8000H, rated at 274 MW, is a direct scale of the 50 Hz SGT5-8000H. The design of the SGT6-8000H is strictly based on Siemens proven aerodynamic scaling rules. A scaling factor of 1 : 1.2 is being applied consistently over the entire cross section of the turbine. The only exception is the combustion system, where exactly the same components, such as burners and baskets, are used as in the 50 Hz model. In order to reflect the reduced mass flow of approx. 1 : 1.44, 12 rather than 16 can-combustors are used on the 60 Hz model. Based on this approach with multiple other well proven examples in our company as reference, validation efforts for the SGT6-8000H can be based on the comprehensive information gained during the SGT5-8000H test program and will require only limited additional efforts to fully prove entire integrity of the 60 Hz model.

Therefore, the first unit will be installed in the Test Center of our Berlin factory in 2011 and be subject of a 6 months test program. As of submission of this paper, detail design of the SGT6-8000H was already finalized and assembly of the first unit completed, with production of further engines in progress.

Summary

After significant long term investment for design, manufacturing and product validation with prove of its superior performance, the SGT-8000H series and the SGT5-8000H based combined cycle power plants were meanwhile successfully introduced to the market (Fig. 11).

What seemed to be impossible at time of launch of the program, achieving more than 60% combined cycle efficiency, has been designed, manufactured, installed and proven during initial operation in reality.

Not only that efficiency and performance of gas fired generation technology was shifted beyond existing borders, Siemens 8000H technology adds operational flexibility beyond existing F Class technology. It can be summarized as “Beyond 60% – Pioneering H Class Efficiency at world class flexibility”.

Based on final detailed evaluation of test data and comparison with design predictions, Siemens Energy is now able to offer world class performance of the 8000H product line for full commercial application as follows:

Fig. 11

Gas Turbine Rating	SGT5-8000H	SGT6-8000H
Output	375 MW	274 MW
Efficiency	40%	40%
Combined Cycle Rating	SCC5-8000H 1S	SCC6-8000H 1S
Output	570 MW	410 MW
Efficiency	> 60%	> 60%

In summary it can be concluded, that approx. 20 years after introduction of today's F Class gas turbine and combined cycle technology, Siemens new advanced 8000H Class represents the most advanced and modern technology for economic and environmental friendly gas fired power generation.

The new 8000H product line and its implementation into a state-of-the-art Combined Cycle Power Plant is the result of a long term commitment during a multi year program with significant financial and manpower investment.
It shows Siemens commitment to meet customer expectations and continue the successful partnership for improved customer value.

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