Siemens mature gas turbines: Answers for 21st century operator demands with proven technology
1 Introduction

Siemens AG started the development of the SGT5-2000E – formerly V94.2 – in the late 1970s. Since then, the turbine has been continuously updated, using an evolutionary approach, to ensure a highly reliable engine, whilst at the same time maintaining a high class of technology and securing the possibility of retrofitting all versions of the engine. This development approach has been greatly appreciated by the market. More than 500 SGT5-2000E engines from Siemens and its licensees and more than 100 SGT6-2000E 60 Hz engines have been installed.

This market success over the last 3 decades has only been possible due to the constant developments made according to the challenging market and customer requirements. In the last 5 years the energy markets have changed dramatically. Current requirements for fossil power plants, especially in the European market, are determined by the strong contribution of renewable sources to the overall electricity production. To fulfill these requirements, fossil power plants must be able to start very fast and reliable. In addition, during operation, the highest levels of flexibility are expected in order to be able to quickly adjust the load according to the grid requirements, e.g. rapid changes in the power output during operation from base load to very low loads, especially overnight, where steam is needed and electricity is not.

Siemens developed a built-in feature for its E-class turbine to meet these requirements. This is available in new units as well as upgrade solutions for the existing fleet. This paper presents recent technology enhancements and ongoing development efforts to adapt the operational performance of fossil power plants to the demanding power generation market with very low level electricity costs.
2 Siemens E-class development path

Siemens has continuously developed nine service packages (SP) for their E-class engine over 35 years. The excellent characteristics of the OEM fleet such as availability of 95.0%, reliability of 99.4% and starting reliability of 96.8% speak for the high quality of the turbine. Figure 1 shows the development path of the service packages and the corresponding technological improvements.

![Siemens E-class service packages](image)

**Fig. 1: Siemens E-class service packages**

The E-class developments comprise both enhanced parts technology as well as improved service concepts. The enhanced parts technology focused not only on performance increases, such as power output and efficiency improvements, but also on new and innovative materials. They therefore mitigate the risk for plant owners and operators. A volatile operating regime in particular, such as peaking or primary and secondary frequency support, may have a huge impact on wear and tear to the parts. Siemens has, therefore, focused not only on the excellent performance of their gas turbines but also on their operational reliability.
Siemens has developed several modernization and upgrade products on the basis of market and customer feedback, as well as constant monitoring of their power plants. Nowadays different markets require different operating regimes. While the majority of the gas turbine fleet in Europe did run at base load before the year 2011, the operation regime has changed to either intermediate or partial load. These operating mode changes led to significant technological and economic constraints. The need to modify and upgrade the gas turbines thus became a high priority not only for plant operators but also for Siemens as a manufacturer in order to ensure continued, high-security.

Almost every part of the gas turbine was involved in further developments. The following improvements, for example, were successfully implemented in several units around the world:

- Enhanced blades and vanes Si3D
- Power Limit Increase (PLI)
- Wet Compression (WetC)
- Part Load Upgrade
- Fast Load Gradient
- Fuel Conversion

The importance of these developments was highly regarded by our customers. In this paper, four of these major upgrades will be presented.
3 Power Limit Increase based on Si3D™ Blades & Vanes

In 2004, the Si3D™ enhanced blades and vanes were introduced onto the market. The new design provides benefits for three different modes in one product:

1. Increased efficiency and moderate power output increase at unchanged fuel consumption
2. Increased efficiency and power output in part load at unchanged exhaust parameters
3. High CC power and CC efficiency increase at increased firing temperature

The successful implementation of an Si3D™ row 1-4 in a CCPP in Finland improved the efficiency of the gas turbine by 1.37% pts or a power output increase of 15MW. Another customer benefit is the reduction of lifecycle costs. More than 50% of the Siemens SGT5-2000E fleet has been retrofitted worldwide. Fleet leader – a plant in Belgium has 41,900 EOH with these enhanced blades. The installation of these blades and vanes as well as HR3 burners is a prerequisite for installing the Power Limit Increase (PLI).

PLI was developed to enhance the operational flexibility of the gas turbine by increasing the power limit. The power limit can be reached either at cold ambient temperatures or with additional power augmentation even at warm ambient temperatures (such as Wet Compression).

The current limit of 173 MW is increased to 186 MW for units with CMF+ and 196.5 MW for units without CMF+. This allows additional generation of electricity during operating conditions which were previously restricted by the power limit. The First Time Validation of the Power Limit Increase was successfully completed in Finland in 2013.
Fig. 3: Power Limit Increase – GT output vs. ambient temperature

Depending on the preconditions of the gas turbine, power output can be increased by:

- up to +23.5 MW (cold ambient conditions)
- up to +13 MW (WetC)
- up to +13 MW (CMF+)

PLI raises the load limit setting and thus enables the utilization of existing power potential especially at low ambient temperatures, PLI itself, however, does not produce any additional power and does not increase efficiency.

### 4 Operational Flexibility

Due to increasing renewable power generation and decreasing power prices, the operational flexibility of a power plant is of utmost importance to plant operators. The original design of a combined cycle power plant was, in many cases, an operating mode at base or intermediate load. However, volatile generation of renewable power demands a fast and flexible response to the energy market.

Gas-fired power plants are also influenced by the environmental aspect of part load operation with compliant emissions (NOx and CO). At 2015 United Nations Climate Change Conference in Paris, France, 195 countries agreed to reduce emissions as part of plans to reduce greenhouse gases. New emission standards will become legally binding by no later than 2020. Our customer therefore raised the issue of extended requirements for flexible plant operation. These requirements resulted in two modernization concepts which enhance the operational performance to ensure the best possible plant economics.
4.1 Part Load Upgrade

The development of this product focused on increasing the part load behavior of the whole GT while remaining within the allowed emissions limits by optimizing the combustion temperature and extending the premix operating mode.

![Optimized Emission Profiles after Part Load Upgrade](image)

**Fig. 3: Optimized Emission Profiles after Part Load Upgrade**

The upgrade strategy is to optimize the combustion temperature for low CO emissions and extend the premix operating mode for low NOx emissions, thus increasing the part load behavior of the whole GT and remaining within the allowed emissions limits. At 34% of GT power, the turbine managed to keep CO emissions below 10ppmv and NOx emissions below 25ppmx. With these measures, customers can operate their plant at part load and in compliance with the government regulations. Furthermore, the Part Load Upgrade (PLU) has various benefits, such as the reduction in fuel consumption and the increased Secondary Frequency Response (SFR) readiness compared to the standard part load and shut-down, as well as the possibility of a faster response to the market needs and increased maintenance intervals which reduces the annual maintenance costs.
4.2 Load Gradient

The SGT5-2000E has three different load gradients. The technical concept is to increase the existing load gradients from 15/14 MW/min currently to 30/27 MW/min (50 / 60 Hz). The fast load gradient itself can be used for GT start-up time reduction (turning gear to base load) and for ramp-up time reduction (part load to base load).

![Start-up procedure SGT5-2000E with the new load gradient of 30MW/min](image)

In phase 1, the start-up frequency converter put the GT to full speed. Within 4.5 minutes the GT is synchronized and an initial load jump takes place (phase 2). Phase 3, 5 and 6 shows clearly how an increased start-up ramp-up rate of 30 MW/min reduces the GT start-up time to baseload from 14.5 min to about 10 min. Another benefit of the fast load gradient, if required by the operator, is the quicker change between part load and base load. This feature is especially beneficial for grid stabilization requirements and for further product combination
with part load operation, in order to allow greater flexibility while operating between part load and base load.

Fast Load Gradients do not require any new hardware and can therefore be implemented during any outage type (Major Outage, Hot Gas Path Inspection, Minor Inspection) without extending the outage time. Operating benefits such as fuel savings, less emissions and flexible operation to lower start-up and shut-down costs as well as increased benefit from Ancillary Services (e.g. Primary and Secondary Frequency Response) resulting from higher availability, utilization fees and spinning reserve credits. Depending on the market environment and customer grid contracts, increased profits through the use of high-price energy markets (Intra-Day Spot Market) may be possible. The improved start-up times allow a potentially higher dispatch rate.

Both the Part Load Upgrade and the Fast Load Gradient are excellent product combinations to increase operational flexibility.

5 Fuel Flexibility

In recent years the price and the availability of fuel has been volatile in different regions and countries. The dependence of operators on fuel suppliers is, therefore, an economic consideration. Operators communicated a strong need to switch to an alternative fuel / back-up fuel due to the increasing fuel costs or limited fuel resources.

SGT5-2000E can be operated with a high variety of fuels. In very general terms, the following fuels may be fired in Siemens gas turbines SGT5-2000E according to the standard GT operation manual using the hardware and software currently available:

- Natural gas
- Light fuel oil
- Heavy fuel oil

In addition to the above-mentioned fuels, the following fuels can be used for combustion. These special fuels do not meet the working media requirements according to the standard GT operation manual but are already successfully in operation in STG5-2000E gas turbines:
Naphtha
Synthetic gas
Liquid natural gas
Coal gas

Siemens has even already prepared several feasibility studies for alternative fuels such as biodiesel, methanol, vegetable oil and sour gas. For firing these special fuels the gas turbine auxiliary equipment and forwarding systems must be developed and burner tests must be carried out prior to the implementation in the customer’s gas turbine.

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(x) Feasible in general, related to project specific requirements

Fig. 5: Multi fuel capabilities of STG5-2000E

Mixtures of listed fuels are also feasible on a project-specific basis if there is a limited availability of unconventional fuel gases or their price increases. STG5-2000E class gas turbines are capable of online fuel switchover between the listed gases or liquid fuels.

Any fuels outside of Siemens specifications are subject to site-specific plant evaluation.
6 Outlook

The increased challenges in the global energy market, especially in Europe, require new operating regimes and a high degree of flexibility with regard to economical business scenarios for many fossil power plants. In recent years, Siemens Power Generation has undertaken significant efforts to modernize the SGT5-2000E gas turbines that have been in operation for many years and to maintain their competitiveness for plant operators. The SGT5-2000E, characterized as a robust gas turbine with extremely good rapid start-up and proven technology, has further potential for upgrading.

As an example, the next development step of the Si3D turbine blades and vanes for stages 1 and 2, called “Si3D™ enhanced”, is already part of the Siemens modernization portfolio. The new generation offers a further improved blades and vanes package with significantly enhanced parts durability.

However, current market feedback demands even greater improvements for the STG5-2000E from equipment suppliers like Siemens. Whether power plant operators choose to upgrade their gas turbine for improved plant flexibility, fuel flexibility or increased efficiency – Siemens is committed to continuous development in thermal power plant technology.

![Fig. 6: STG5-2000E – Next Innovation Steps](image)

In 2019, the next service package will be ready for implementation – as always, retrofittable to the existing gas turbine fleet and utilizing the latest technologies from the new unit products.
7 References

Modernization of Siemens Gas Turbines as Part of Power Plant Service.

Gas Turbine Modernizations Flexible Service Modernization Products
for the Asian Market.

[3] PowerGen Europe, 6/2012:
Powerful products for an enhanced flexibility of Gas Turbines

[4] Russia Power, 3/2013:
Power Limit Increase of Gas Turbines through Modernization

Fuel applications in modern gas turbines
### 8 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AG</td>
<td>German abbreviation of form of company Aktien Gesellschaft</td>
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<td>CC</td>
<td>Combined Cycle</td>
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<td>CCPP</td>
<td>Combined Cycle Power Plant</td>
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<td>CHS</td>
<td>Ceramic Heat Shields</td>
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<td>CMF</td>
<td>Compressor Mass Flow</td>
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<td>CO</td>
<td>Carbon Monoxide</td>
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<td>GT</td>
<td>Gas Turbine</td>
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<td>HCO</td>
<td>Hydraulic Clearance Optimization</td>
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<td>EOH</td>
<td>Equivalent Operating Hours</td>
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<td>MAC</td>
<td>Maintenance Concept</td>
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<tr>
<td>MW</td>
<td>Mega Watt</td>
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<td>NOx</td>
<td>Nitric Oxide</td>
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<td>OEM</td>
<td>Original Equipment Manufacture</td>
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<td>OTC</td>
<td>Outlet Temperature Control</td>
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<td>PLI</td>
<td>Power Limit Increase</td>
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<td>PLU</td>
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<td>Secondary Frequency Response</td>
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<td>SGT</td>
<td>Siemens Gas Turbine</td>
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<td>Si3D</td>
<td>Siemens 3 dimensional aerodynamic blades design</td>
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<td>SP</td>
<td>Service Package</td>
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<td>WetC</td>
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