SGT5-2000E – Latest Service Improvements for Optimized Operations, Maintenance and LNG Fuel Conversion Upgrade
# Table of Contents

1. Introduction ............................................................................................................ 3
2. Siemens large gas turbine portfolio ........................................................................ 4
   2.1 SGT5-8000H – breaking one world record after another ....................................... 4
   2.2 SGT5-4000F – advanced technology with more than 20 years of operation ....... 6
   2.3 SGT5-2000E – proven and robust technology for today and the future ............ 7
3. Siemens Large Gas Turbine Services SGT5 – 2000E ............................................ 9
   3.1 Power Limit Increase based on Si3D™ Blades & Vanes ................................. 10
   3.2 Fuel flexibility ................................................................................................. 11
4. Outlook ................................................................................................................. 14
5. References ............................................................................................................ 15
6. Abbreviations ....................................................................................................... 16
7. Disclaimer ............................................................................................................ 17
1 Introduction

The African power market faces a huge electricity demand challenge. Within the next decade African economies will grow disproportionately. Secured power production is a pre-condition for continuous development of African industries as well as ensuring access to a power supply for private households.

This paper focuses on the Siemens gas turbine portfolio and the latest service R&D programs for the SGT5-2000E gas turbine frame (formerly known as V94.2), which are particularly relevant with respect to the needs of the African power market:

- Latest upgrades to optimize power output,
- Efficiency and fuel flexibility, as well as
- Measures to reduce overall maintenance effort and costs.

African countries require region-specific solutions for power generation and distribution. It is becoming increasingly important to operate power plants with the best possible reliability and availability independent of the operational mode, e.g. peak application or base load operation. These markets demand fuel flexibility and operational flexibility for grid stability to ensure sustainable power supply. This is linked directly to customized service concepts matching the need for maximized uninterrupted operation.

The objective of this paper is to introduce the broad range of power generation gas turbines from Siemens as well as its service concepts and solutions for ambitious projects. With proven technology, high reliability and flexible performance, our products are suitable for all industrial and economic African markets.
2 Siemens large gas turbine portfolio

Siemens gas turbines are designed and tailored to help meet our customers’ challenges in a dynamic market environment, a proven technology with over 6,750 installed heavy duty, industrial and aeroderivative gas turbines.

The products offer low lifecycle costs and an excellent return on investment.

Fig. 1: Siemens gas turbine portfolio

Siemens gas turbines are suitable for a wide range of applications:

- Power generation application for utilities,
- Independent power producers, oil and gas, and industrial users such as chemicals, pulp and paper, food and beverages, sugar, automotive, metalworking, mining, cement, wood processing and textiles.
- Mechanical drive applications for oil and gas, and the chemical industry.

2.1 SGT5-8000H – breaking one world record after another

On May 19 2011, Siemens made technological history when the "Ulrich Hartmann" power plant unit at Irsching Power Station in Bavaria was handed over to the customer after setting a
new world record for energy conversion efficiency, attaining 60.75% net efficiency in a test run. This marked the first time ever that the 60% barrier had been broken. Over the years since then, the unit has proven its reliability and availability. Inspections have yielded no negative findings, in each case confirming the unit's service life expectancy. Siemens has since sold seventy-nine H-class turbines.

Fig. 2: SCC5-8000H Lausward

Including the new "Fortuna" unit at Lausward Power Station in Düsseldorf, nineteen H-class turbines are now in commercial operation which, all in all, have smoothly delivered more than 200,000 equivalent hours of trouble-free operation and have exceeded customer expectations. The experience gained from five years of commercial operation accumulating some 5,000 starts has proven useful in many areas. Systematic efforts to further develop not only the turbine series but also the overall plant technology and engineering have enabled three world records to be achieved:

- 61.5% net efficiency,
- 603.8 MW electrical generating capacity from a single-shaft configuration,
- 300 MWth of district heat extracted from a single power plant unit.
In addition to all the world records, Siemens has the world’s largest H-class fleet running on LNG today with more than 100,000 fired hours. Customers worldwide rely on this proven and flexible technology, and this makes the Siemens H-class an adequate solution for electricity production.

2.2 SGT5-4000F – advanced technology with more than 20 years of operation

Since the introduction of the SGT5-4000F in 1996 in Didcot, United Kingdom, Siemens has continuously invested in evolutionary design improvements. With the 4000F engine, Siemens established a new advanced F-class segment and maintained the competitiveness of this frame not only by investment in significant increases in power and efficiency.

Siemens has also enhanced additional flexibility features of the gas turbine to meet the needs of different regions around the globe. The 4000F engine is capable of being operated from -50° C to up to 55° C ambient temperature due to its robust design. 4000F reference projects extend from extremely cold areas to very hot and dry or hot and humid regions. The 4000F
fleet in projects with hot ambient conditions presently numbers more than 80 gas turbines, and has already accumulated over 3 million EOH.

Over the past years, Siemens has improved the fuel flexibility of the SGT5-4000F in different ways. For gaseous fuel, the limits for high sulfur content were extended in an extensive research and development program in order to keep the basic engine configuration unchanged. Additionally, the latest burner hardware was proven to allow for wider operation bandwidth of Wobbe indices. With its advanced burner systems and dual fuel capability, the SGT5-4000F is also capable of meeting the World Bank emission standards even without water injection and derating.

2.3 SGT5-2000E – proven and robust technology for today and the future

The demands placed on power generation by heavy duty gas turbine power plants vary depending on the different situation and boundary conditions in the various countries in Africa. Due to the gas respective fuel oil supply situation, grid situation and energy consumer capability, the focus is on decentralized power generation by industrial-sized applications up to E-class level power plants. In addition to potential F and H-class projects in the north and south of Africa, there is rising demand for E-class technology due to the limited grid situation, for example in Nigeria, Zambia, Mozambique, Ivory Coast and Ghana. Apart from a few exceptions, first-time costs (CAPEX) including financing conditions are key decision criteria but the life cycle cost analysis (OPEX) is also becoming increasingly relevant for business case calculations.

In addition to CAPEX and OPEX, customized service concepts including retrofittability and maximum availability and reliability are also considered in business case evaluations. With respect to performance figures, in addition to the specific price ($/kW), the efficiency of the power plant is the key to success for investors, producers and operators, and ultimately the end customers. Recent gas turbine research and development activities have resulted in a significant power output and efficiency increase which is available for new units as well as for retrofitting to most of the existing fleet. This evolutionary design is based on more than three decades of OEM fleet experience and design philosophy to preserve the robust and mature design of the Siemens E-class. Siemens supports and believes in a future E-class market in Africa and will continue to pursue the development of new units based on customer
needs. Siemens AG started development of its SGT5-2000E gas turbine frame in the early 1980s. Since then, the frame has been continuously updated, using an evolutionary development approach that keeps the engine’s technology on a state of the art level while minimizing technical risks and maximizing engine reliability.

Fig. 4: SGT5-2000E – fleet development and recent developments

Over the years, a global fleet of more than 500 engines has been installed by Siemens and its licensees. Both the newly built engines and also the operation and maintenance concepts for the SGT5-2000E undergo a continuous development process, constantly improving operational capabilities and keeping the total lifecycle cost of the SGT5-2000E at a benchmark level for the industry. The results of an extensive R&D program led to further improvement of the already most successful upgrade product, the Siemens innovative 3D blades and vanes (Si3DTM). The Si3DTM blading now allows for a higher power limit and also comes as a Si3DTM enhanced version with considerably improved robustness and hence significantly reduced maintenance costs. We have also shown the latest developments in increasing power output – such as the compressor mass flow upgrade (CMF+) – and optimization of operational flexibility. Finally, we will give an overview of our latest operational experiences with a variety of different fuels.
Siemens Large Gas Turbine Services SGT5 – 2000E

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% and starting reliability of 96.8% speak for the high quality of the turbine. The SGT-2000E series fleet’s overall best-in-class reliability exceeds 99%. Our installed fleet has accumulated more than 17 million equivalent operating hours.

The R&D developments comprise both enhanced parts technology as well as improved service concepts. The enhanced parts technology focuses not only on performance increases, such as power output and efficiency improvements, but also on new and innovative materials. It therefore mitigates the risk for plant owners and operators. In particular, a volatile operating regime (such as peaking or primary and secondary frequency support) may have a huge impact on wear and tear to the parts. For this reason, Siemens has focused not only on the excellent performance of their gas turbines but also on their operational reliability.

Nowadays, different markets require different operating regimes. 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 levels of safety.

Fig. 5: SGT5-2000E – service developments
Almost every part of the gas turbine was involved in further developments. The following improvements 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. Four of these major upgrades will be presented in this paper.

### 3.1 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 with unchanged fuel consumption
2. Increased efficiency and power output at part load with unchanged exhaust parameters
3. High CC power and CC efficiency increase at increased firing temperature

The successful implementation of a 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 in lifecycle costs. More than 50% of the Siemens SGT5-2000E fleet has been retrofitted worldwide. The fleet leader – a plant in Belgium – has 41,900 EOH with these enhanced blades. 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. 6: 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 allows utilization of existing power potential, especially at low ambient temperatures. However, PLI itself does not produce any additional power and it does not increase efficiency.

### 3.2 Fuel flexibility

In recent years, the price and the availability of fuel has been volatile in different regions and countries. For this reason, the dependence of operators on fuel suppliers is 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 wide variety of fuels. In very general terms, using the hardware and software currently available the following fuels may be fired in Siemens gas turbines SGT5-2000E according to the standard GT operation manual:

- 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
- Liquefied natural gas
- Coal gas

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

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<tr>
<td>(all fuels of this category can be used w/ one configuration)</td>
<td>- x x</td>
<td>x x</td>
</tr>
<tr>
<td>(in general this fuels can be fired with project specific adaptation of standard system)</td>
<td>x - x</td>
<td>x x</td>
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<tr>
<td>Syngas System &amp; Combustion Configuration</td>
<td>(x) (x)</td>
<td>x (x) (x)</td>
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<tr>
<td>Standard Fuel Oil System &amp; Combustion Configuration</td>
<td>x x (x)</td>
<td>- (x)</td>
</tr>
<tr>
<td>Project Specific Fuel Oil System &amp; Combustion Configuration</td>
<td>(x) (x)</td>
<td>x -</td>
</tr>
<tr>
<td>Crude / Heavy Fuel Oil System &amp; Combustion Configuration</td>
<td>x x (x)</td>
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**Legend:**
- x Feasible
- (x) Feasible in general, related to project specific requirements

**Fig. 7: Multi fuel capabilities of STG5-2000E**
Mixtures of listed fuels are also feasible on a project-specific basis if there is limited availability of unconventional fuel gases, or if their price increases. Any fuels outside of Siemens specifications are subject to site-specific plant evaluation.

STG5-2000E gas turbines are capable of **online fuel switch-over** between the listed gases or liquid fuels.

![Fuel Change Over Phases and GT Load for F- and E-class](image)

**Fig. 8: GT load level switch-over time**

During operation the gas turbine load will be reduced to 75% load within approx. 10 minutes. In this mode the turbine will run in mixed-fuel operation before fuel switchover is realized within approx. 3 minutes. At upload operation, the turbine will again run in fuel pre-mixed operation for another 10 minutes. The online switchover takes approx. 23 minutes; switchback takes a further 3 minutes.

Fuel changeability is a unique feature of Siemens gas turbines and also available as a service upgrade for already-installed units. In the current market environment, this capability supports the operating flexibility that is absolutely required.
4 Outlook

The increased challenges in the global energy market 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. However, current market feedback demands even greater improvements for the STG5-2000E from equipment suppliers such as 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. 9: STG5-2000E – Innovation Steps**

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.
5 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
### 6 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 ‘Aktiengesellschaft’</td>
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<td>CAPEX</td>
<td>Capital Expenditures</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>CMF</td>
<td>Compressor Mass Flow</td>
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<tr>
<td>EOH</td>
<td>Equivalent Operating Hours</td>
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<tr>
<td>FTI</td>
<td>Fire Temperature Increase</td>
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<tr>
<td>GT</td>
<td>Gas Turbine</td>
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<tr>
<td>HCO</td>
<td>Hydraulic Clearance Optimization</td>
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<tr>
<td>HR3</td>
<td>Hybrid Rückschlagfrei (German for ‘flashback free’) version 3</td>
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<tr>
<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>kMW</td>
<td>Kilo Mega Watt</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>MAC</td>
<td>Maintenance Concept</td>
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<tr>
<td>MW</td>
<td>Mega Watt</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacture</td>
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<tr>
<td>OPEX</td>
<td>Operational Expenditures</td>
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<td>PLI</td>
<td>Power Limit Increase</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<td>SCC</td>
<td>Siemens Combined Cycle</td>
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<td>SGen</td>
<td>Siemens Generator</td>
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<tr>
<td>SGT</td>
<td>Siemens Gas Turbine</td>
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<tr>
<td>S3D</td>
<td>Siemens 3 dimensional aerodynamic blades design</td>
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<tr>
<td>SP</td>
<td>Service Package</td>
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<tr>
<td>SPPA</td>
<td>Siemens Power and Process Automation</td>
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<tr>
<td>SST</td>
<td>Siemens Steam Turbine</td>
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<tr>
<td>VGB</td>
<td>Vereinigung der Großkesselbesitzer (German Assoziation for Power and Heat Generation)</td>
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<tr>
<td>WetC</td>
<td>Wet Compression</td>
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7 Disclaimer

These documents contain forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as “expects”, “anticipates”, “intends”, “plans”, “believes”, “seeks”, “estimates”, “will” or words of similar meaning. Such statements are based on our current expectations and certain assumptions and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond the control of Siemens, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among other things, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens worldwide, changes in business strategy and various other factors. More detailed information about certain of these factors is contained in reports filed by Siemens with the SEC, which are available on the Siemens website, www.siemens.com and on the SEC’s website, www.sec.gov. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated. Trademarks mentioned in these documents are the property of Siemens AG, its affiliates or their respective owners.