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Senoko Power Station CCP2 performance increase with focus on efficiency

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Answers for energy.

Content

Abstract	4
Introduction	5
Overview about the Senoko Power Station	6
Siemens innovative 3D optimized turbine blades and vanes (Si3D) stages 1 and 2	6
Si3D stages 1 and 2 upgrade scope GT22	7
References	7
Upgrade results GT22	8
Conclusion	9
Permission for use	9
Disclaimer	9

Abstract

The Senoko Power Station is the largest power station in Singapore, owned by Senoko Energy Pte Ltd. The installed capacity consists of 500 MW thermal steam plant plus 1,945 MW combined cycle plants (CCPs), with a further 860 MW currently under construction and due online in 2012, and 190 MW open cycle gas turbines (PPGT).

The four Siemens SGT5-2000E (V94.2) 131 MW simple cycle gas turbines for plants 1 and 2 were commissioned in 1990/91 in two separate blocks. In 1994, the turbines were converted into two combined cycle blocks, each of 425 MW capacity (CCP1 and CCP2).

To increase the efficiency of the CCP2, the customer decided in December 2010 to upgrade one of the gas turbines – GT 22 – with the Siemens innovative 3D optimized (Si3D) turbine blade and vane for stages 1 and 2, during the 133 k major outage.

The installation including a pre- and post-outage performance test was successfully accomplished on schedule between December 2010 and February 2011.

After the upgrade, the baseload efficiency of the gas turbine was increased by +1.51 %-pts. and the baseload power output was increased by +5.2 MW. The complete block continues to operate within its design limits.

The turbine upgrade assists creating "Green MW" which supports Singapore's "Green Plan 2012". Based on its design figures this upgrade will reduce CO₂ emissions by approximately 21,000 t/year.

Due to the improved blade and vane base materials along with optimized cooling air consumption, lower scrap rates are expected compared to the earlier design.

Introduction

Gas turbine design and manufacturing technologies have advanced greatly in the years since the SGT5-2000E (V94.2) engines were originally designed and installed.

Some specific examples would include:

- Advances in design and modeling technologies enable us to better predict mechanical and thermal stresses both at steady state and during transient conditions, component heat transfer, component temperature distributions and component peak metal temperatures at the surface and within the component, and natural frequencies and vibratory response prediction for the many vibratory modes of a component.
- Refinement of design criteria based on years of design and operation experience enable us to develop optimum component and system designs that produce the best possible performance while still meeting the design target life requirements.
- Advances in material, cooling and coating technologies allow engines to operate at higher firing temperatures for enhanced power and efficiency, and allow hot gas path components to operate under more rigorous conditions with longer intervals between inspections and comparable or longer design target lives than on older, lower firing engine designs.

The technologies as described above already enable the Siemens' advanced gas turbines to operate at higher performance levels. These technologies are now used to develop upgrades and component enhancements for the existing fleet of the mature gas turbines. Siemens as the Original Equipment Manufacturer (OEM) has extensive experience with the SGT5-2000E (V94.2) fleet and is aware of possible component issues and areas for potential improvement. Siemens has incorporated improvements into our current line of replacement parts as well as upgrade packages.

One of the innovative solutions offered by Siemens for the SGT5-2000E (V94.2) to help customers to improve their operating plant competitiveness and profitability is the Si3D blades and vanes upgrade for turbine stages 1 and 2.

To increase the efficiency of the CCP2, the customer Senoko Energy Pte Ltd. decided in December 2010 to upgrade one of the gas turbines (GT22) with the Si3D turbine blade and vane design for stages 1 and 2 during the 133 k major outage.

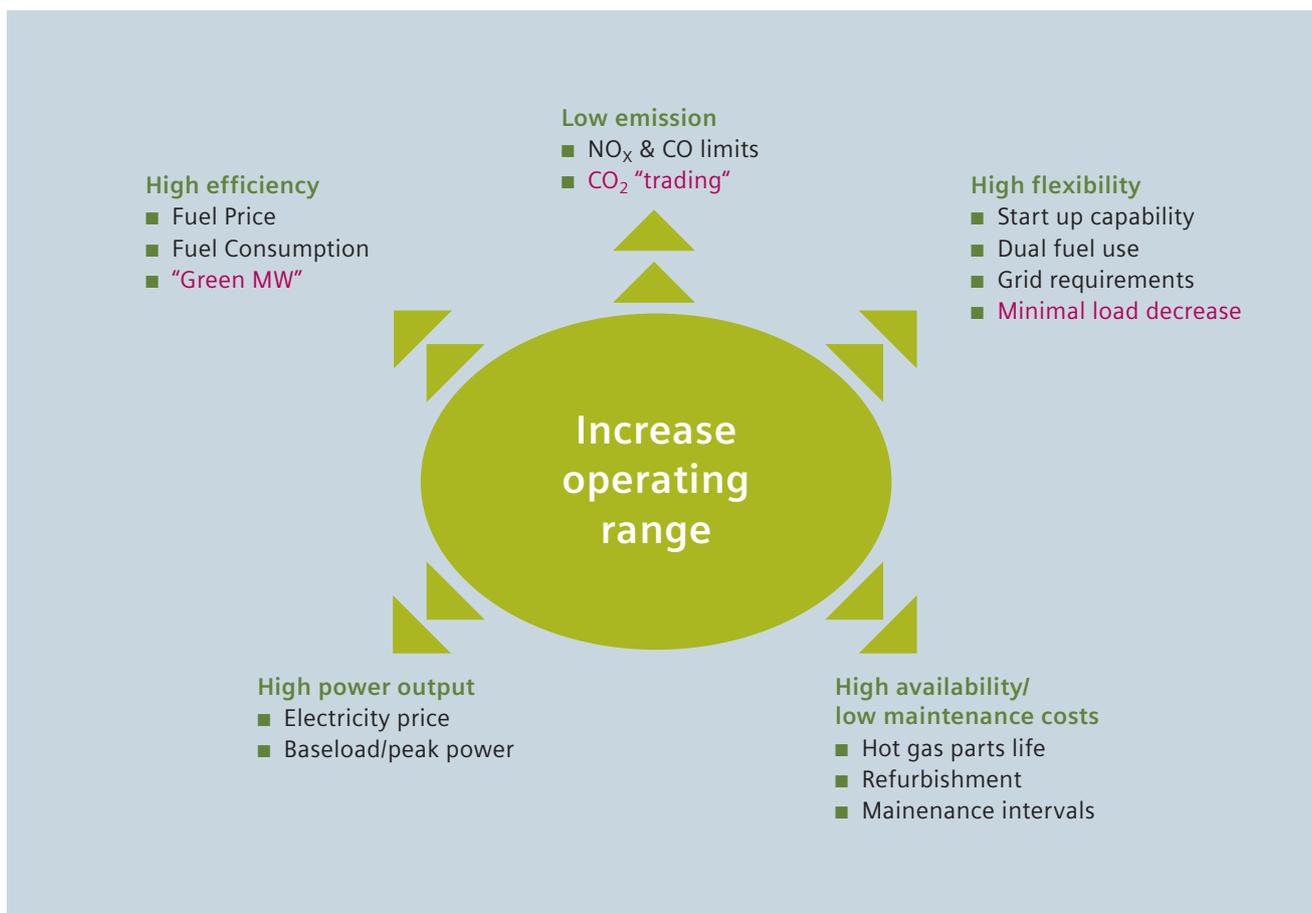


Fig. 1: Market challenges for SGT5-2000E (V94.2) modernization

Overview about the Senoko Power Station

The Senoko Power Station is the largest power station in Singapore. It is located in Senoko, Sembawang and was commissioned in 1976. It is owned by Senoko Energy Pte Ltd., formerly known as Senoko Power Ltd.

The plant development stages are as follows:

- **Senoko Steam Plant Stage II**
(currently under repowering into 2 x 430 MW gas-fired Combined-Cycle Plants CCP 6 & 7. Completion in 2012)
Original Plant – Hitachi Steam
Manufactured in Year – 1979
Capacity – 750 MW
- **Senoko Steam Plant Stage III**
Plant – Hitachi Steam
Year – 1983
Capacity – 500 MW
- **Senoko Combined-Cycle Plants 1 & 2 (formerly Stage I)**
Plant – Siemens CCP
Year – 1996
Capacity – 850 MW
- **Senoko Combined-Cycle Plants CCP 3 – 5**
Plant – Alstom CCP
Year – 2004
Capacity – 1,095 MW



Fig. 2: Senoko Power Station CCP 1 and CCP 2

Senoko Power Station thermal plant was developed in 3 stages between 1976 – 1983. To meet Singapore's power needs and to strengthen the system reliability, 4 units of 131 MW open cycle gas turbines were installed in 1990–1991. To further increase the plant efficiency, these gas turbines were extended into 2 blocks of CCPs of 425 MW capacity each. This was Singapore's first CCP and was completed two months ahead schedule.

The repowered CCPs 3 – 5 became commercially operational in 2004 after its successful conversion from the conventional Senoko Stage I (comprising three 120 MW oil-fired steam plants) into the most efficient environmentally friendly three 365 MW CCPs.

The Senoko Stage II 3 x 250 MW oil-fired steam plants are currently under repowering construction to be converted into 2 x 430 MW CCPs. This project is expected to be completed in 2012.

In its early years, the plant used crude oil as fuel to generate steam for its turbines; however, this was replaced by natural gas piped from Terengganu on the east coast of Peninsular Malaysia from 1992. Fuel oil is still in use as a back-up fuel.

The plant's only standing concrete chimney belongs to Stage III and is 182 meters high. This is the tallest structure in the northern part of Singapore and one of the tallest structures on the island. It is clearly visible across the Johor Straits and in most parts of Johor Bahru. The plant's second chimney which belongs to Stage II was demolished in July 2010 as part of the repowering process.

Siemens innovative 3D optimized turbine blades and vanes (Si3D) stages 1 and 2

The power output and efficiency of a gas turbine is highly dependent on the quality of converting thermal energy into mechanical energy. This is conducted in the turbine section. The influencing factors in this section are the aerodynamic design of the airfoils and the shroud areas where leakage air is dissipated. The airfoil design of the first versions of the SGT5-2000E (V94.2) gas turbine was based on two dimensional design methods. Using current state-of-the-art three dimensional design techniques the airfoils of the turbine section have been modified reducing the aerodynamic losses. In addition, the application of riddle seals in the shroud area has reduced leakage air dissipation. As a result, there is less entropy generated, thereby improving the efficiency of the process.

A considerable portion of the cooling air extracted from the compressor section is consumed to ensure the life time of the components in the turbine section.

An additional improvement of the Siemens innovative 3 dimensional design is a reduction of the cooling air consumption. This has been achieved by using a new design material with higher thermo-mechanical resistance and



Fig. 3: Si3D blades on turbine stages 1 and 2

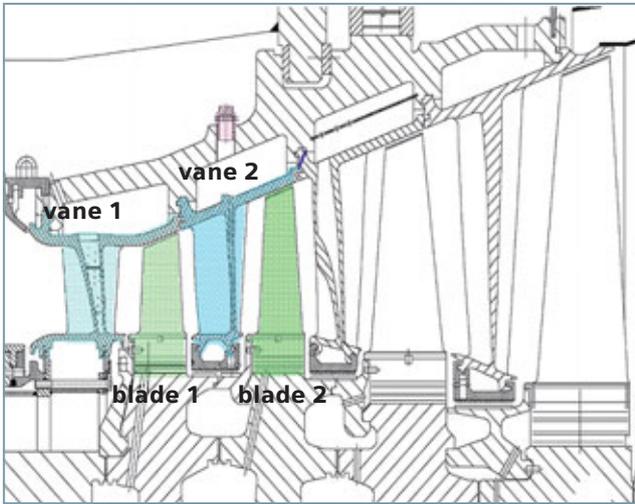


Fig. 4: Si3D stages 1 and 2

the latest internal cooling air path design. Furthermore an advanced thermal barrier coating has been applied to reduce the temperature of the base material.

As a result of this cooling air consumption reduction more compressor air can be utilized for the combustion process, increasing the overall efficiency of the gas turbine. An additional feature of these improvements are extended maintenance intervals and longer service life for the overall gas turbine.

Si3D stages 1 and 2 upgrade scope GT22

The Si3D upgrade from Siemens Energy is just one of the many innovative modernization packages available.

The scope of this upgrade includes for GT22:

- Newly profiled 3 dimensional aerodynamic design for stages 1 and 2
- Optimized cooling air path for the first two stages
- New Ni-based blade and vane materials
- Internal aluminization coating on the first two turbine stages
- Advanced thermal barrier coatings on the first two turbine stages
- New coatings on turbine blade stage 3
- New improved ruffle seal strips for the turbine vanes stages 1 and 2 due to a new platform design
- New improved lean design U-shaped seal ring for turbine vane 2
- New throttle sleeves on turbine vane carrier to reduce cooling air consumption
- Control optimization of the corrected turbine outlet temperature
- Site specific instrumentation and control (I&C) modifications based on the existing Teleperm XP/ Simodyn I&C configuration



Fig. 5: Cooling air throttle in vane 2 section

References

Siemens has broad experiences with the Si3D blades and vanes upgrade for turbine stages 1 and 2.

Operating plants upgrade business*

- 19 units SGT5-2000E (V94.2) with Si3D blades and vanes stages 1 and 2 are in operation world wide. These 19 units accumulated more than 230,000 Equivalent Operating Hours (EOHs) and more than 4,400 starts. The fleet leader unit accumulated more than 40,000 EOH's since the Si3D implementation.
- Another 19 units SGT5-2000E (V94.2) with Si3D blades and vanes stages 1 and 2 are ordered world wide.

New plants business*

- Since 2007 Si3D blades and vanes stages 1 and 2 are state-of-the-art for SGT5-2000E (V94.2) gas turbines of new plants business.
- 21 units SGT5-2000E (V94.2) of new plants business equipped with Si3D blades and vanes stages 1 and 2 are in operation world wide and accumulated more than 119,000 EOHs and more than 3,100 starts.
- 10 units SGT5-2000E (V94.2) of new power plant business equipped with Si3D blades and vanes stages 1 and 2 are ordered world wide.

* As of April 2011

Upgrade results GT22

During the negotiation phase it was agreed with the customer to focus the upgrade on efficiency. However, due to the significant improvement of efficiency in the turbine section, the power output of the gas turbine was also increased. Test results of Si3D retrofits on GT22 have demonstrated a gas turbine efficiency improvement of +1.51 %-pts along with an additional +5.2 MW of power output.

The turbine inlet temperature (TIT) was not changed. The specific fuel consumption is significantly reduced, hence significantly lowering the operation costs.

The biggest environmental benefit is based on the reduction in CO₂ emissions by approximately 21,000 t/year.

A gas turbine delta performance test, considering of two separate tests before and after the implementation of Si3D stages 1 and 2, was performed at Senoko GT22. The measured gas turbine gross efficiency of both test was compared in order to verify the fulfillment of the thermodynamic delta guarantee. The test before the major outage was conducted on December 3rd 2010; the test after the major outage was performed on January 29th 2011.

The tests were based on calibrated instruments. Test procedure was used according to ISO 2314.

For the verification of the guarantees the following operation mode was tested: fuel gas dry, inlet guide vane fully open, outlet temperature control active and combined cycle operation.

The gas analysis of the Opengrid Laboratory was used to determine the fuel composition as needed for the performance calculation. Under these conditions and without applying neither aging factors nor test tolerances, the GT 22 gross efficiency increased by +1.51 %-pts.. Reference conditions:

- Ambient pressure: 1013 mbar
- Relative humidity: 60%
- Ambient temperature: 30°C
- Inlet pressure loss (total): 5 mbar
- Exhaust pressure loss (static): 26 mbar
- Lower heating value: 47,210 kJ/kg
- C/H ratio: 3,271
- Speed: 50 Hz
- Power factor: 0.8

The final results (corrected to reference conditions) are as follows:

GT 22		Before outage 12/03/2010 11:05 am – 12:05 pm	After outage 01/29/2011 02:05 pm – 3:15 pm	Delta
Gas turbine gross efficiency as measured (already corrected to nominal power factor)	[%]	30.68	32.31	
Gas turbine gross efficiency corrected to reference conditions	[%]	30.59	32.10	1.51 %-pts.

All other parameters (e.g. aging) were assumed to be constant for both performance tests and respective set to be constant.

Prior to the execution and / or the evaluation of the performance tests at Senoko GT 22 Senoko Energy Pte Ltd. and Siemens agreed on the following boundary conditions:

- The tests were based on the “GT Test Procedure for Thermal Acceptance Test of GT Delta Performance, Siemens SGT5-2000E Senoko, Singapore”. ISO 2314 “Gas Turbine – Acceptance Tests” provides additional information.
- Calibrated instruments were used for the evaluation of the test results. Only for the gas turbine speed, the excitation current and the fuel volume flow operational instruments were used.
- The fuel mass flow was determined with an ultrasonic flow meter, which is installed near the engine. The fuel gas pressure and the fuel gas temperature were taken with calibrated equipment near the flowmeter, whereas the volume flow was taken from the operational log.
- Power factor conversion was performed by electrical calculation.
- For both tests, each three fuel samples were taken during the one-hour tests, one at the beginning, one at the middle and one at the end of each test. All samples were sent to Opengrid Europe in Germany for analysis. For the calculation of the fuel mass flow the average of these three samples were used.



Fig. 6: Si3D blades and vanes on turbine stages 1 and 2

The compressor had an offline compressor wash prior to the tests. The inlet guide vane position for 100% airflow was checked and measured prior to the tests.

For determination of the thermodynamic state of the working fluid international recognized gas property tables (i.e. Keenan & Kayes, Landolt & Börnstein) were used. Specific enthalpies serve to calculate air and exhaust mass flows according to ISO 2314.

Efficiency had to be corrected as test conditions deviated from reference conditions. All the corrections were done by using unit specific correction curves. The power output used for the determination of the efficiency was corrected to the nominal power factor of the generator.

Conclusion

Recent improvements in turbine technology have provided major benefits such as increased performance and improved reliability and availability. All these benefits make a gas turbine modernization project attractive and highly beneficial for aging power plants.

The economics of modernization and upgrade activities compare very favorably to new plant capacity purchase. The incremental cost per kilowatt of power derived from upgrades can be very low because the upgraded parts which enable the higher performance typically involve the highest-wear shortest-life components and longer-life components that are reaching the end of their useful life.

Main benefits for Senoko Energy Pte Ltd. GT22 based on the Si3D stages 1 and 2 upgrade on a glance:

- Approved and fully validated Siemens OEM technology
- Gas turbine baseload efficiency increase (+1.51 %-pts.)
- Retrieval of "lost" MW and additional gas turbine baseload output improvement (+ 5.2 MW)
- Fast payback of investment after commissioning of the Si3D optimized turbine blades and vanes
- The turbine upgrade assists creating "Green MW" which supports Singapore's "Green Plan 2012". Based on its design figures this upgrade will reduce CO₂ emissions by approximately 21,000 t/year.
- Installation during the normal 133 k major outage
- Instrumentation and control modifications based on the existing configuration
- Reduced life cycle costs (lower scrap rates due to the new Ni-based blade and vane materials along with optimized cooling air consumption compared to standard blades and vanes expected)
- The gas turbine is further working within the design limits
- "Fit for the future" (most upcoming Siemens upgrades are based on Si3D technology)

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