Adaptation of the SGT6-6000G to a Dynamic Power Generation Market

Ed Bancalari
- Manager, SGT6-6000G Frame

Pedy Chan
- Project Engineer, SGT6-6000G Frame

POWER-GEN International 2005 – Las Vegas, Nevada
December 6-8th

SIEMENS

Abstract

This paper describes the U.S. market conditions in which the SGT6-6000G was designed and its evolution to accommodate the current and future market requirements. The U.S. market drivers during the SGT6-6000G design were deregulation and replacing the old base load generation, such as old coal plants, with high efficiency/output power and low emissions combined cycle plants. The SGT6-6000G was originally designed primarily for base load operation, but also with sufficient cyclic life margin on its critical components to make it inherently suitable for cyclic operation. The current natural gas price and the power generation overcapacity created by the gas turbine boom have resulted in a competitive situation which places a premium on minimized operational costs and maximized flexibility. This phenomenon resulted in a situation where usually the nuclear and coal plants are dispatched first and only then the most economical and operationally flexible gas turbine plants would be dispatched. Instead of operating full time at base load, SGT6-6000G is now required to operate predominantly in the cyclic mode. To address the market shifts and customer requirements, improvements were made to the gas turbine and the plant to enhance its capability for low cost, flexible operation. These improvements were focused on increased cycling capabilities, increased reliability, improved part load and base load performance, reduced emissions (especially at part load), increased time between inspections and reduced plant startup times.

Introduction

The market drivers during the SGT6-6000G gas turbine design (1993-1995) were moving toward deregulation and replacing old base load generation, such as old coal-based power plants, with clean and efficient combined cycle plants. Fears of deregulation in the North American electricity market caused prospective plant buyers to look at plants that could be installed and commissioned in a short time, rather than the 6 years required to permit and build a coal plant. The belief at the time was that the new high efficiency, low emissions, clean fuel plants would be the economic and environmental choice and displace coal plants. Because of its high efficiency (58% in CC application compared to the then state-of-the-art CC plants with 54-55% efficiencies), it was intended that the SGT6-6000G would be operated primarily at base load. In the late 1990's there was an increased demand for electric power. Since natural gas prices were low (about $2.50/MMBtu) and there was a large demand for increased power generation, many gas turbines were bought for simple and combined cycle operation. By 2002, the demand for power was subsiding (in some areas there was overcapacity), and the availability and price of natural gas (which increased to above $6/MMBtu) combined with low electricity prices caused the gas turbine combined cycle plants to be operated at only 30% average capacity (50-60% for the SGT6-6000G). The increase of natural gas prices caused combined cycle plants to move lower in the dispatch order and therefore into a cycling duty mode. In this environment, the amount of time the merchant plants could operate profitably was reduced.

In response to the changed market requirement for more cyclic operation and to further enhance its competitive advantage, design changes and improvements were incorporated into the SGT6-6000G engine. Other enhancements are planned for the future to allow even more operating flexibility. Customer feedback through user groups, direct feedback and the Diagnostics Centers have allowed Siemens to focus on development programs which are directly aligned with customer requirements.

SGT6-6000G was readily adaptable to cyclic/flexible operation due to its inherent design features and this capability was further improved by enhancements incorporated over the last several years. The following enhancements were developed in cooperation with SGT6-6000G operators in order to address their short and long term needs:

- Design improvements were incorporated into the combustor basket to reduce emissions, improve reliability and increase the time between inspection intervals.
- The steam cooled transition was redesigned to reduce metal temperatures and extend inspection intervals based on both hours and starts.
- Compressor and turbine sealing were improved, thus improving performance and reducing emissions.
- Cooling designs on the first four rows of turbine airfoils were optimized.
- The rotor cooling air temperature was optimized to enhance operational flexibility.
- Enhanced turbine disk material, which is utilized in the existing V-fleet, was instituted.
- The exhaust system was redesigned to improve performance and service life.
- Trip Factor number (number of equivalent starts for each engine trip) was reduced.
- Starting was changed from mechanical motor start to static start utilizing a Static Frequency Converter (SFC) to improve starting reliability and reduce capital cost.
- Gas turbine and plant controls were optimized and simplified to improve the engine's operational flexibility and starting reliability.

Operating Experience

The prototype SGT6-6000G engine was started up in April, 1999. This plant was initially in a simple cycle configuration with the once-through auxiliary boiler producing transition cooling steam. After the extensive verification test program was completed, the plant went into commercial operation in March, 2001. The plant was converted to combined cycle configuration by the end of 2001. The first SGT6-6000G in CC application achieved commercial operation in April, 2001, at the PG&E Millennium Plant in Charlton, Massachusetts. References 10 to 13 provide additional information on SGT6-6000G operational experience.

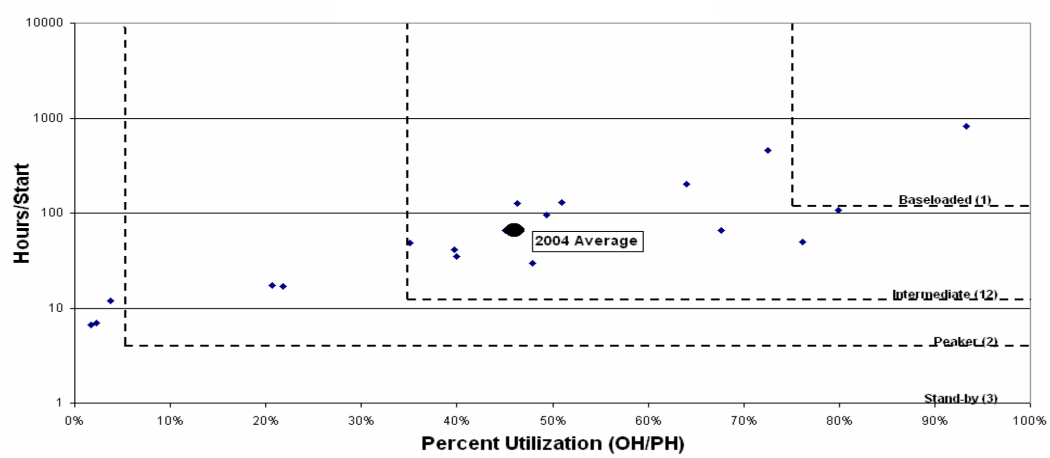

Figure 1. SGT6-6000G Fleet Operating Profile in 2004

SGT6-6000G engines have operated in different modes, from peaking duty, through cycling/load following, to base load duty (see Figure 1). They demonstrated excellent operational and starting reliability shortly after their introduction, over a wide ambient temperature range, on both gas and oil fuels. At one site, during the second commercial operation year, the gas turbine operated at 10% capacity and had 123 successful starts with a 95% starting reliability (see Reference 13). The SGT6-6000G functioned satisfactorily in this highly cyclic operational mode. Many financial and insurance institutions considered 8,000 operating hours on a new frame a benchmark that defines the product as "mature". The operating fleet has reached and surpassed this milestone, since currently 10 engines have accumulated more than 8,000 hours. By the middle of 2005, the lead unit has been in commercial operation for more than 22,000 hours, and the total fleet has accumulated more than 155,000 operating hours. The fleet operating hours are being accumulated at a fast rate by the 20 units in commercial operation and will accelerate with new units coming on line in the near future. Figures 2 and 3 show the increase with time of the total fleet operating hours and the number of operating units.

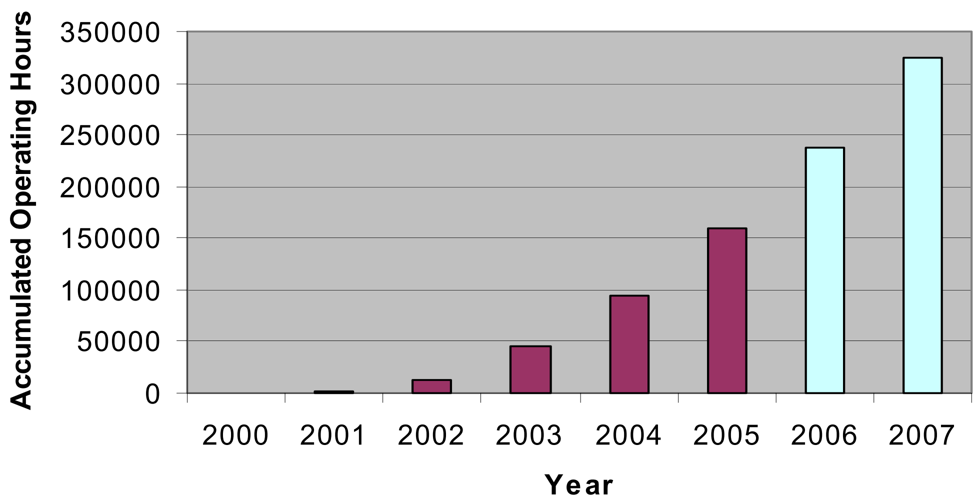

Figure 2. SGT6-6000G Fleet Operating Hours

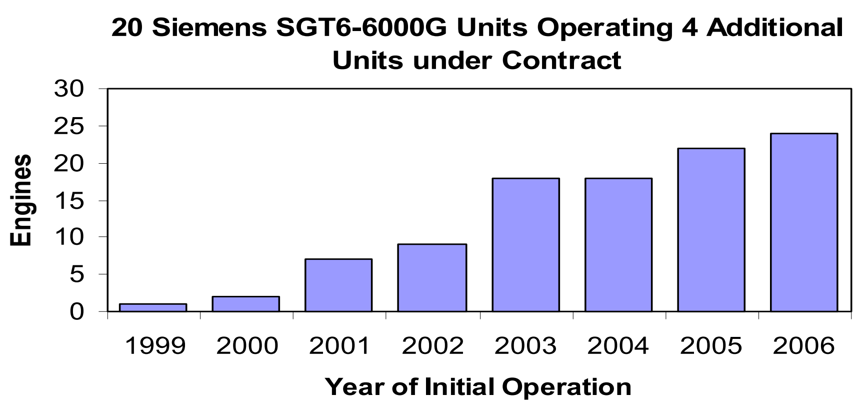

Figure 3. SGT6-6000G Units in Operations

Changing Market Environment

There was a dramatic change in the U.S. electricity generation market conditions from the time that SGT6-6000G was being designed and the present. In the mid 1990's, there was a perception of under-capacity and that the drive toward deregulation would replace the old base load generation, such as coal-based plants, with clean and efficient combined cycle plants. Purchasing decisions were being made by studying economic data, electricity capacity and dispatch curves. The decisions to buy new generation were made in an open market environment, with many merchant plant owners making similar decisions without being able to foresee the overcapacity and fuel price scenario that would develop. The result was that the total electric capacity growth in the U.S. since 1997 has exceeded peak growth demand by three times (see Figure 4). Combined cycle plants supplied 65% of this new capacity. This resulted in decreased overall combined cycle Capacity Factor, which is defined as unit operating hours divided by hours the unit is available for operation (see Figure 5). In 2003, more combined cycle plants were used in peaking and intermediate duty range, than in base load. The electricity-generating plant's ability to improve its dispatch rate depends on demand growth, economic dispatchability and operational flexibility. The new electric generation capacity in the U.S. has exceeded the peak demand growth in recent years by significant margins. Thus, there was a dramatic increase in Reserve Margins, with the national average exceeding 30% margin in 2004 (see Figure 6). On average, the nation will not require significant additional capacity until 2009.

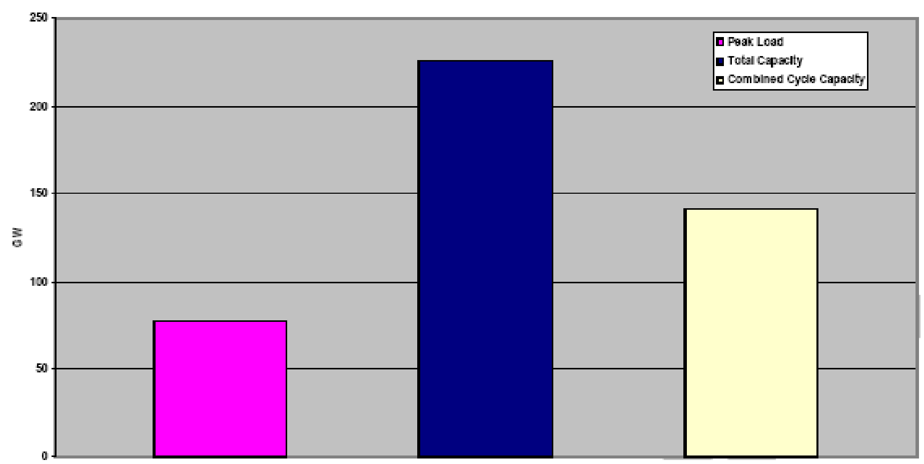

Figure 4. Total Change in U.S. Peak Load and Capacity

Units that excel in economic dispatchability and operational flexibility will dispatch at a higher rate than other competing units in this overcapacity market. Economic dispatch is modeled by a Market Segmentation Model, in which units are dispatched in the order of Variable Production Cost (VPC). Fuel cost and the variable Operation and Maintenance (O&M) cost for each unit determine the VPC value. Small changes in VPC can significantly impact the projected dispatch rates for each unit. Fuel cost is directly related to the gas turbine efficiency and increases in efficiency will not only improve the revenue per megawatt hour but will also increase the hours that the unit is dispatched in a competitive market. Improving the O&M cost will also result in a lower VPC, greater dispatchability and an increase in net cash flow. Dispatchability depends also on the unit's operational flexibility. Units that are capable of following load changes, economically cycling on and off, and possessing other flexibility characteristics are particularly important in the peaking and intermediate duty modes and will have an advantage in the current market. The design enhancements and changes incorporated into the SGT6-6000G improved both its economic dispatchability (due to higher efficiency and lower parts/maintenance costs, hence lower VPC) and operational flexibility, thus enhancing its dispatch rate.

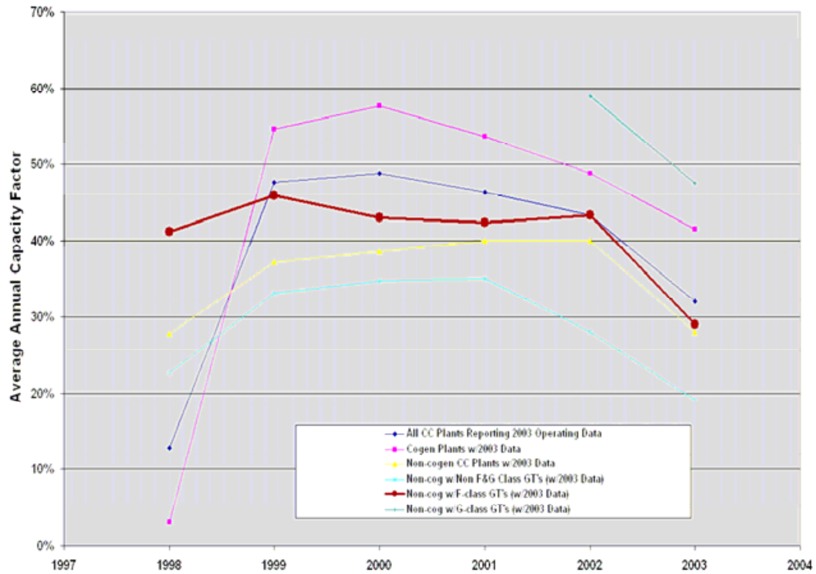

Figure 5. Combined Cycle Plant Capacity Factor

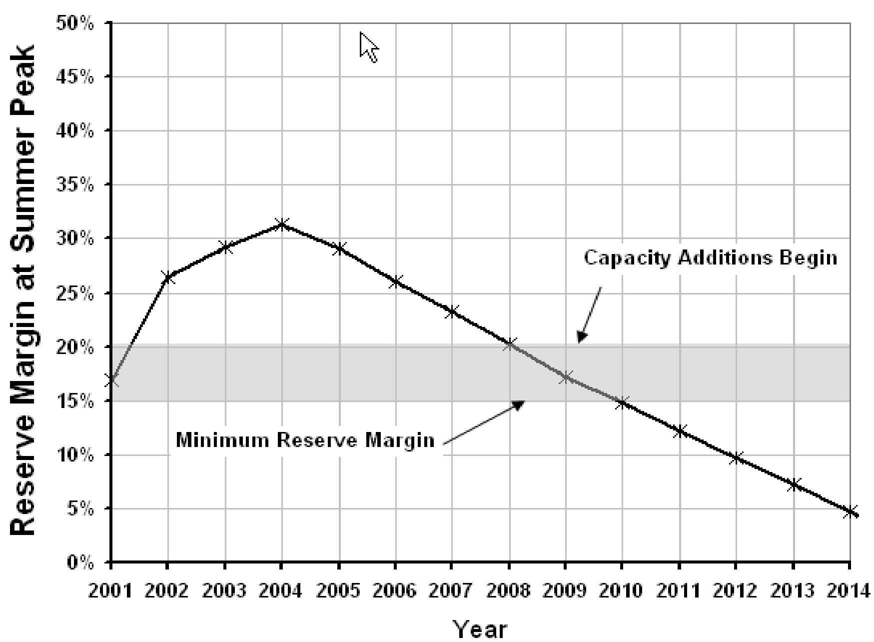

Figure 6. Projected Average U.S. Reserve Margins (Including Retirements & Displacements)

Engine Adaptation to Market Conditions

To operate profitably, it is very important to our current and future customers that the SGT6-6000G gas turbine allows them the operational flexibility demanded by the ever changing market conditions. Operational flexibility not only includes the ability to operate the gas turbines safely, efficiently and with acceptable emissions in different operating modes, but also the ability to operate on different fuels, starting reliability, and to be at load in the shortest time possible. Above all, this flexibility must strive to not penalize performance, component lives, maintainability and emissions.

Design enhancements have been incorporated into many of the currently operating SGT6-6000G machines to increase efficiency, reduce maintenance cost and further improve operational flexibility, in response to the changing market conditions requirement for cyclic operation at minimized cost. The enhancements involved reducing emissions, improving performance, availability/reliability and extending inspection intervals. The enhancements addressed the combustion system, sealing, turbine, rotor, exhaust system, and controls. Table 1 summarizes these efforts and associated effects.

Component Design Enhancements	Effect							
	Improved Perfor-mance	Reduced Emissions	Improved Part Life	Reduced Maintenance Costs	Improved Starting Reliability	Improved Reliability	Enhanced Operation Flexibility	Retrofita-bility
Combustion System Improvements		X	X	X	X	X	X	X
Enhanced Transition		X	X	X		X	X	X
Sealing:								
a. Compressor	X					X		
b. Combustor / Transition / Turbine	X	X		X		X		X
Turbine Blade Tip Clearance Reduction	X							X
Enhanced Cooling on First Two Turbine Stages	X		X	X		X		X
Exhaust System	X		X	X		X	X	X
Controls				X	X	X	X	X
Trip Factor Reduction				X		X	X	X

Table 1. Design Enhancements for Operational Flexibility

Combustion System

The combustion system is an important component in allowing low emission operation at base and part load. In the past, high part load CO emissions and the time intervals between combustor inspections limited operational flexibility. Over the last five years, continuous combustion system enhancements have been incorporated and the gas turbines are operating at 25 ppm NOx (at 15% O_2) and part load CO <10 ppm (at 15% O_2) while increasing the inspection interval. The inspection interval, which was originally 8,000 hours, has now been extended to 12,000 hours with enhanced combustor and transition parts. The time between overhauls may be improved by a factor of 3 for units operating in a high starts mode, by combining the effect of Trip Factor reduction (described below) and the combustor inspection interval increase to 12,000 hours/800 equivalent starts (from 8,000 hours/400 starts).

The 25 ppm NOx value was achieved by improved sealing, elimination of transition seal cooling flow and using the SGT6-5000F basket. Using the same basket on two engine frames results in reduced development risk, increased rig testing time and accelerated learning with regard to a standardized design (leveraging common parts). Advanced DLN technologies are targeted to reduce NOx emissions below 15 ppm based on the combustion system which accomplishes 9 ppm in the SGT6-5000F frame.

CO emission is now <10 ppm down to 60% load. With further improvement, the turndown ratio will be reduced to less than 50% load, thus enhancing operational flexibility.

Transitions

The SGT6-6000G transition was redesigned to reduce metal temperature at the hottest part of the transition. The redesign improved transition life (both due to reduced time at temperature and improved LCF life) and will permit future increases in firing temperature. The original transition design has demonstrated 16,000 hours of service life and the redesign, which is already in validation, has a 36,000 hour and 1600 equivalent start design life. This extension of combustor inspection intervals will significantly reduce maintenance costs and increase gas turbine availability for both base loaded and cycling plants.

The steam flow, in a steam cooled transition, can be increased at part load, as required, to enhance transition cooling. The IGVs are closed at part load to reduce CO emissions and improve bottoming cycle performance. This is a considerable advantage over an air cooled design, in which the pressure difference between the cooling air supply and inside the transition is reduced with closed IGVs resulting in reduced cooling air flow and increased transition metal temperatures.

On startup, the SGT6-6000G transition is air cooled up to 20% load. This preheats the piping to above the steam saturation temperature with the warm cooling air. This pipe preheating prevents pipe condensation and moisture ingress during transfer to steam cooling at 20% load. Transition cooling is transferred from steam to air at 20% load when unloading, during load rejection or shutting down. This allows the unit to stay at significant load upon loss of steam flow and also purges the steam cooling system of steam during shutdown.

The advantages of the above cooling configuration compared to startup steam cooling with an auxiliary boiler are:

- No auxiliary or external steam required on startup.
- The elimination of an auxiliary boiler eliminates additional stack emissions and associated permitting concerns. Plant efficiency is also improved by the elimination of auxiliary boiler fuel consumption during standby operation.
- Reduced cost.
  - Reduced maintenance (no additional boiler, pumps, valves, controls, chemical feed, etc.).
  - A complex auxiliary steam supply system with associated negative impact on plant availability is eliminated.
- When a potential operating problem in the steam circuit arises, the gas turbine load can be reduced to 20% and the transition air cooled, while the problem is being resolved.

- The air cooling and purge of the steam system on shutdown prevents moisture accumulation in engine steam cooled components and eliminates the potential for freeze damage.

Sealing

Cooling air and hot gas leakage reduction improves engine performance and durability. Improved performance is even more important now due to high fuel prices. Leakage reduction in the combustion system and the turbine reduces NOx emissions, because with reduced leakage the flame temperature will be lower for the same rotor inlet temperature, which determines engine performance. Reducing or eliminating hot gas leaks will improve component durability, reduce degradation rate, and improves parts' lives in cyclic operation.

Compressor diaphragm sealing was improved by incorporating advanced abradable seals (instead of knife edge seals) to seal the radial gap between the stator housing and the disk rim extensions. This enhancement was validated in the Berlin Test Bed and is now running in a SGT6-5000F.

Spring clips on the combustor basket were redesigned to reduce leakage and improve reliability. The hard seals at transition mouth inner and outer diameters were replaced by flexible seals located outside the gas path to minimize exposure to hot gases. With the flexible seal redesign the circumferential gaps at transition exits were reduced. The redesigned transition seals significantly reduced leakage and NOx and improved seal durability.

Stationary turbine component sealing concepts developed on the existing V-series product line have been transferred to the SGT6-6000G to improve sealing (see Figure 8). These seals also have reduced degradation rate and wear as additional benefits.

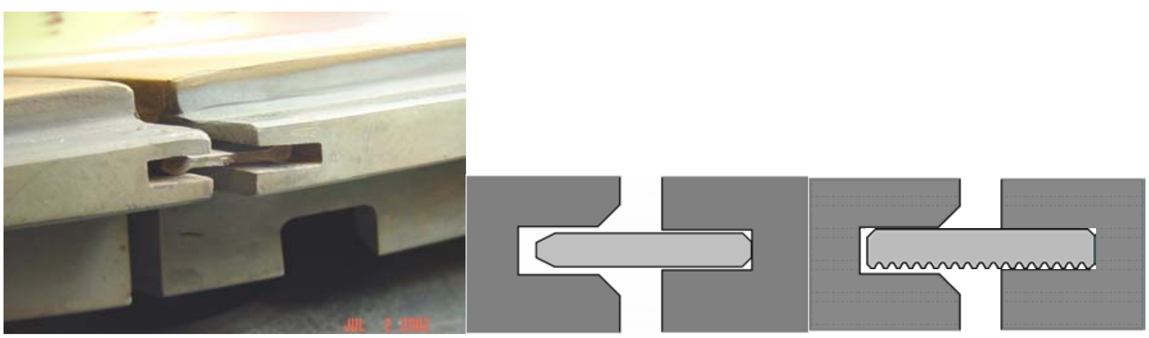

Figure 8. Enhanced Turbine Sealing

Turbine Clearance Optimization

Turbine blade tip clearance and pinch point reduction were achieved by various operational optimizations. The first and second stage blade tip clearances were reduced further by applying improved abradable coating to the stationary ring segments.

The shrouded third and fourth stage blade tip sealing was enhanced by changing the stationary seal honeycomb material and changing the seal configuration. To eliminate the wear on the blade tip seal lands and coating spallation, new tip coating has been applied. These changes will result in tighter tip clearances, reduced hot gas leakage, improved efficiency and increased component life.

Turbine Cooling

First and second stage designs were optimized to reduce cooling air flow, extend total life and reduce repair fallout. These improvements were accomplished through cooling optimizations and through the application of an advanced thermal barrier coating and bond coat.

Exhaust System

The exhaust system was redesigned for increased efficiency (by improving its aerodynamics and reducing exhaust losses) and cyclic life. This redesign, which has now been installed on three units, facilitates low load operation with closed IGVs without causing potential exhaust distress due to the high exit swirl. Closed IGVs help in reducing CO emissions at part load as a result of the increased flame temperature. The additional closure of IGVs along with outlet temperature control can also significantly boost part load combined cycle efficiency, further enhancing the flexibility of the combined cycle plant.

Starting Reliability/Controls

To improve engine starting reliability, an investigation was carried out to identify detractors from good starting reliability. Several detractors were identified. Based on the findings, the advanced Closed Loop Ignition Control (CLIC) system was developed and validated. The ignition system was redesigned in two phases to make it more rugged and reliable. By implementing the CLIC system the starting reliability is targeted to be improved to 97%.

The original engine control system was based on a function of exhaust temperature versus combustor shell pressure. The new outlet temperature correction (OTC) control system uses the relationship between the exhaust temperature and compressor inlet temperature (see Figure 9). The new system provides a tighter control on IGV settings and an increase in part load plant efficiency, as well as eliminating part load NOx drift and removing the need for seasonal combustion system tuning. Outlet temperature correction control has been successfully utilized for over 20 years in the existing V-fleet. It has been in operation in the SGT6-5000F fleet since 2002 (13 engines in operation with OTC, with 11,000 operating hours on the lead unit) and in the SGT6-6000G fleet since 2004.

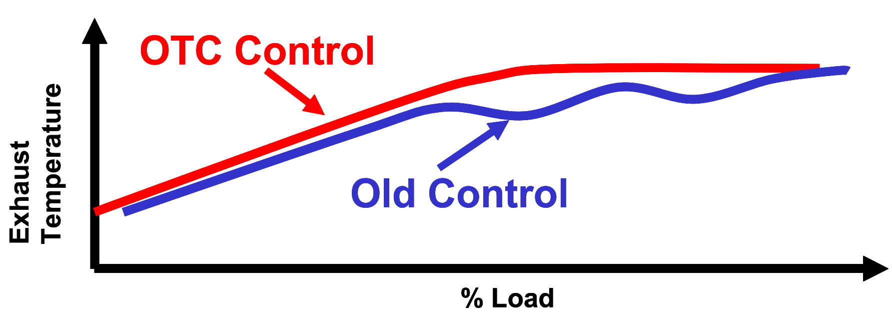

Figure 9. Outlet Temperature Control

The gas turbine control system software was updated to eliminate spurious trips. Since the first engine went into commercial operation, the plant control system evolution has improved its reliability, thus resulting in a reduction in BoP instigated engine trips. This was achieved through cooperation and feedback from operators. Siemens operates three Diagnostics Centers (two in Germany and one in Orlando). Data is collected and automatically processed/analyzed using Artificial Intelligence software and information is provided to operators on impending malfunctions (such as thermocouple drift) and potential hardware issues. The benefits are risk mitigation, increased availability and reduced inspection/outage times.

Trip Factor

Trip Factor is the number of equivalent starts when the engine experiences a trip. For instance, Trip Factor of 20 means that each trip is equivalent to 20 starts. Each engine trip, especially if it is an emergency trip from base load, causes hot end components to experience severe thermal gradients over a short time interval (the turbine airfoil metal temperatures may decrease hundreds of degrees in seconds). The result is a negative impact on hot end parts' mechanical integrity and life. Startups, on the other hand, are slower and turbine components experience a moderate rate of temperature increase and hence much lower thermal gradients. Thus, originally each trip was considered equivalent to 20 starts as to its effect on the gas turbine cyclic life and the inspection interval. The Trip Factor has been reduced from 20 to 8 as a result of component improvements and operational experience. Improving combustion system and turbine component cyclic life also allow reduction in the Trip Factor.

Economic Advantage

The SGT6-6000G satisfies the market requirements for low capital cost, small footprint size, short construction period and low operating costs. Its high efficiency, high power density and demonstrated reliability/availability/operational flexibility make it an attractive economic choice for power generators.

Net present value (NPV) measures the net worth of a plant. It is the difference between the net revenue coming into the plant and the investments made in the plant, which is the algebraic sum of all the discounted net cash flows during the plant life time. A positive NPV, expressed in millions of dollars, means that the plant will be profitable and the higher the value the greater the economic advantage. Figure 10 compares the original W501G engine NPV with that of the current SGT6-6000G for cyclic operating mode. It shows the current engine NPV advantage as percent of total improvement distribution for each contributing factor. This is due to its increased efficiency/output power, increased temporal/cyclical parts life and reduced BoP costs. The following assumptions were made in evaluating the different contributors to the changes in NPV. Combined cycle efficiency and output power were based on a 1X1 CC plant using standardized BoP equipment (such as heat recovery steam generator, steam turbine, condenser, etc.) with similar performance levels. The gas turbine service Long Term Program (LTP) assumed a 20-year LTP contract, which included all part costs, maintenance costs and part fallout rates. The BoP costs represented the actual balance of plant equipment costs that would be impacted directly by the gas turbine. The majority of the design enhancements that were developed are retrofitable to the existing SGT6-6000G fleet. This approach ensures that existing as well as future customers realize the full benefit of advancements and their associated economic advantage. The economic advantage estimates demonstrate that, with upgrades' implementation, the SGT6-6000G will significantly enhance the profitability for our current customers and will become the economic and technical product of choice for future customers.

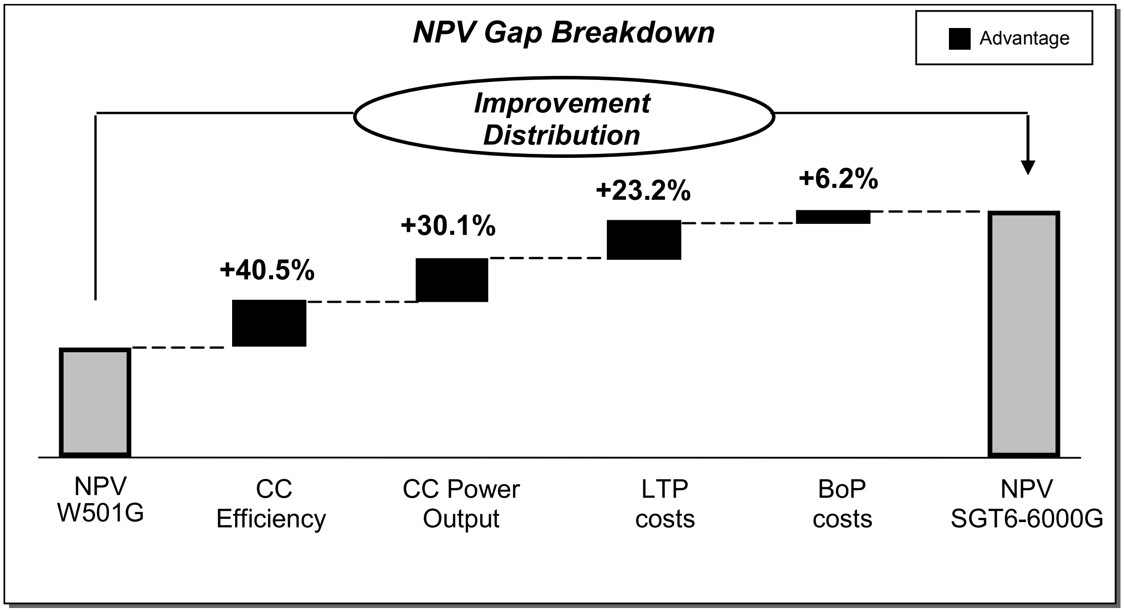

Figure 10. NPV Advantage of Present SGT6-6000G over Original W501G in Cycle Duty

Future Enhancements and Upgrades

SGT6-6000G engine performance and reliability have improved steadily since its introduction. Based on experience with previous models, this trend will continue in the future. Based on SGT6-5000F development history, the SGT6-6000G has a substantial growth potential. For the SGT6-5000F, which was designed and shop tested in the late 1980's and early 1990's, introductory output power was 135 MW. Over the last 15 years a concerted development effort increased both its efficiency and output power to 200 MW, which represents a 48% increase. Over its lifetime a similar improvement in the SGT6-6000G, which was introduced in 1999 at 235 MW, will result in >300 MW output power.

Future SGT6-6000G development will not only concentrate on improvements on performance and emissions, but also on reliability/availability/maintainability, operational flexibility, lower maintenance costs, longer component lives, improved service factors and increased repair intervals. Further enhancements planned for the SGT6-6000G are described below:

1. Single-shaft combined cycle reference power plant is being designed. This concept, with the gas turbine, generator and steam turbine in an in-line arrangement, will improve the plant efficiency and reduce plant cost (see Reference 14). The single shaft concept, plus the incorporation of the advanced Benson™ once-through heat recovery steam generator and several other plant features, will result in startup times that are twice as fast as in a typical current CC plant (see Figure 11).
2. Advanced compressor design for improved performance.
3. Advanced technology combustor, for further reduction in emissions.
4. Ability to burn LNG, to allow more fuel flexibility.
5. Advanced TBC, with lower thermal conductivity and elevated surface temperature capability.

6. Advanced vane and blade cooling.
7. Conical flow path for first two turbine stages for reduced tip clearance. The casing and rotor thermal expansions move in opposite directions resulting in blade tip clearance reduction. This is aided by active rotor shift in a desired direction (as in the V-fleet).
8. Ceramic matrix composite material will be considered for replacing selected metallic components to reduce cooling air usage and hence improve performance and reduce emission.
9. Adaptation of SGT6-6000G for integration into coal-based integrated gasification combined cycle (IGCC) plant, to produce low cost electricity with almost zero emissions. The gas turbine will be developed for syngas and H_2 operation. A proposal was submitted recently to the U.S. Department of Energy, in response to the FutureGen Solicitation, for a 10-year program to develop the SGT6-6000G for integration into an advanced coal-based IGCC plant and to demonstrate its readiness for commercialization.
10. Increased use of common parts with other Siemens frames to leverage development efforts, learning rate and manufacturing capabilities.

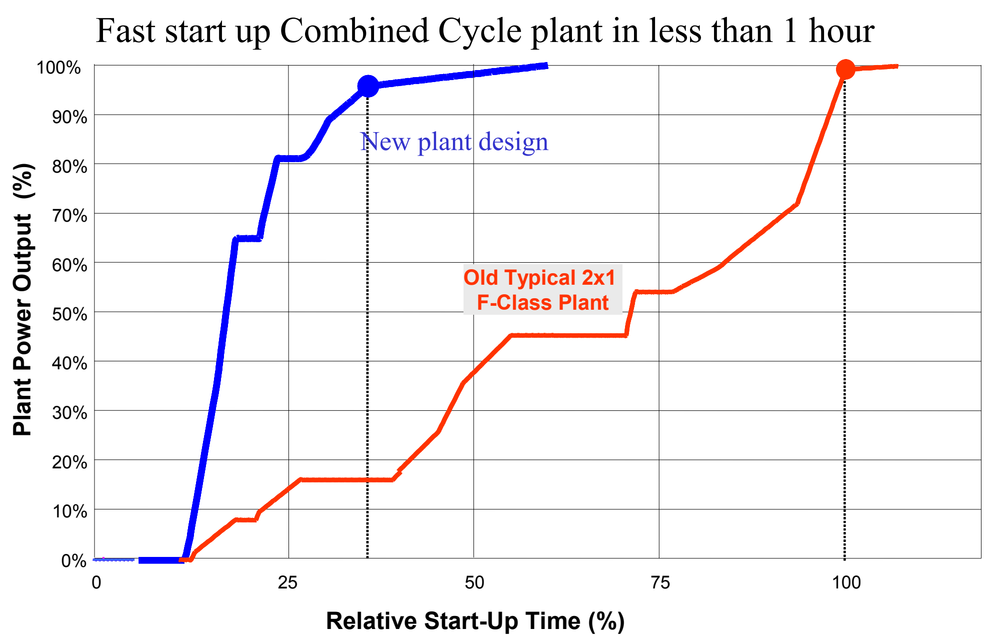

Figure 11. Reduced Combined Cycle Plant Startup Time

Summary

The 20 SGT6-6000G engines in commercial operation have accumulated more than 155,000 hours and have demonstrated excellent reliability and availability for a recently introduced design. Although the SGT6-6000G was originally intended for base load operation, it has been enhanced to operate successfully in the cyclic mode in response to current market forces. The ability to operate in this mode was made possible by the inherent mechanical integrity and durability of the original design, as well as a concerted effort, over the last few years, to incorporate design changes which improved efficiency, reliability, LCF life, parts' lives and reduced emissions and life cycle costs. Combustion system inspection intervals have been increased from 8,000 hours/400 equivalent starts to 12,000 hours/800 equivalent starts and Trip Factor has been reduced from 20 to 8. These improvements have significantly reduced maintenance costs and increased engine availability in both base load and cycling duty cycles.

To improve the SGT6-6000G further and thus enhance its future competitive position in the market place and add customer value, improvements are planned in compressor aerodynamics, combustion system, turbine cooling, sealing, starting reliability and controls. SGT6-6000G will be adapted for IGCC integration into future IGCC plants.

Due to its inherent design features and enhancements incorporated since its introduction, the SGT6-6000G gas turbine has proven its capability in a competitive market environment, by demonstrating the ability to operate in load follow and daily cyclic modes without sacrificing performance, reliability or availability. Therefore, it is a very efficient and reliable platform for low cost electricity generation, which is very important to our customers in the current highly competitive market conditions and steadily rising fuel prices.

REFERENCES

1. Scalzo, A.J., Bannister, R.L., DeCorso, M., Howard, G.S., 1994, "Evolution of Westinghouse Heavy-Duty Power Generation and Industrial Combustion Turbines", ASME Journal of Engineering for Gas Turbines and Power, 118, pp. 316-330.

2. Southall, L., McQuiggan, G., 1995, "New 200 MW Class 501G Combustion Turbine", ASME Paper 95-GT-215.

3. McQuiggan, G., 1996, "Designing for High Reliability and Availability in New Combustion Turbines", ASME Paper 96-GT-14.

4. Janssen, M.J., Joyce, J.S., 1996, "35-Year Old Splined-Disc for Large Gas Turbines", ASME Paper 96-GT-523.

5. Bohrenkämper, G., Reiermann, D., Höhne, G., Lingner, U., 2005, "Upgrades of The Proven SGT5-2000E/SGT6-2000/E Gas Turbine Models", Russia Power Conference, 9-11 March 2005, Moscow, Russia.

6. Little, D.A., Cobley, K., 1996, "Application of Aeroengine Aerodynamic Design Codes to Industrial Gas Turbine Design", ASME Paper 96-GT-280.

7. Diakunchak, I.S., Gaul, G.R., McQuiggan, G., Southall, R.L., 2002, "Siemens Westinghouse Advanced Turbine Systems Program Final Summary", ASME Paper GT-2002-30654.

8. Antos, R.J., 1995, "Westinghouse Combustion Development, 1996 Technology Update", POWER-GEN International 1995.

9. Gaul, G.R., Diakunchak, I.S., Dodd, A.M., 2001, "The W501G Testing and Validation in the Siemens Westinghouse Advanced Turbine Systems Program", ASME Paper 2001-GT-0399.

10. Antos, R., DeRosa, P., Wolfe, B., McManus, M.T., 2001, "The W501G Product Description and Operational Experience-Proven Power for the Global Market", POWER-GEN International 2001.

11. Antos, R., Diakunchak, I., Wolfe, B., 2002, Product Enhancements and Operational Updates on Advanced Technology W501 Gas Turbines", POWER-GEN International 2002.

12. Bancalari, E., Diakunchak, I.S., McQuiggan, G., 2003, "A Review of W501G Engine Design, Development and Field Operating Experience", ASME Paper GT 2003-38843.

13. McQuiggan, G., Bancalari, E., Miller, S., 2004, "The Siemens Westinghouse W501G Engines Demonstrated Performance with Proven and Planned Enhancements, POWER-GEN International 2004.

14. Baumgartner, R., Wolt, E., 2002, Advanced Technology Single-Shaft Combined-Cycle Reference Plants for High Efficiency and Operating Flexibility", POWER-GEN International 2004.