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SGT6-5000F
For
IGCC Application

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Abstract

The SGT6-5000F is a 60Hz, ~200 MW, F-Class, Siemens Gas Turbine that can be configured to operate on low calorific syngas fuel in an IGCC (integrated gasification combined cycle) application. The SGT6-5000F modified for an IGCC application combines >700,000 hours of syngas combustion turbine operation with years of reliable gas turbine operation [the SGT6-5000F fleet currently has 207 engines in operation with >6.7 million hours]. A two-stage combustor, capable of burning syngas and natural gas, was designed, tested, and applied to the SGT6-5000F(3) gas turbine. This paper describes the configuration of the SGT6-5000F and the operation and control strategy for producing reliable power in an IGCC application.

1 Introduction

The platform for the 60Hz IGCC gas turbine is the SGT6-5000F which currently has a fleet of 207 engines with >6.7 million hours of operation. The SGT6-5000F(3) is a 200 MW gas turbine with a 16-stage compressor and 4-stage turbine. Displayed in Figure 1 configured with a syngas combustor, this gas turbine will operate on low calorific fuel in an IGCC application.

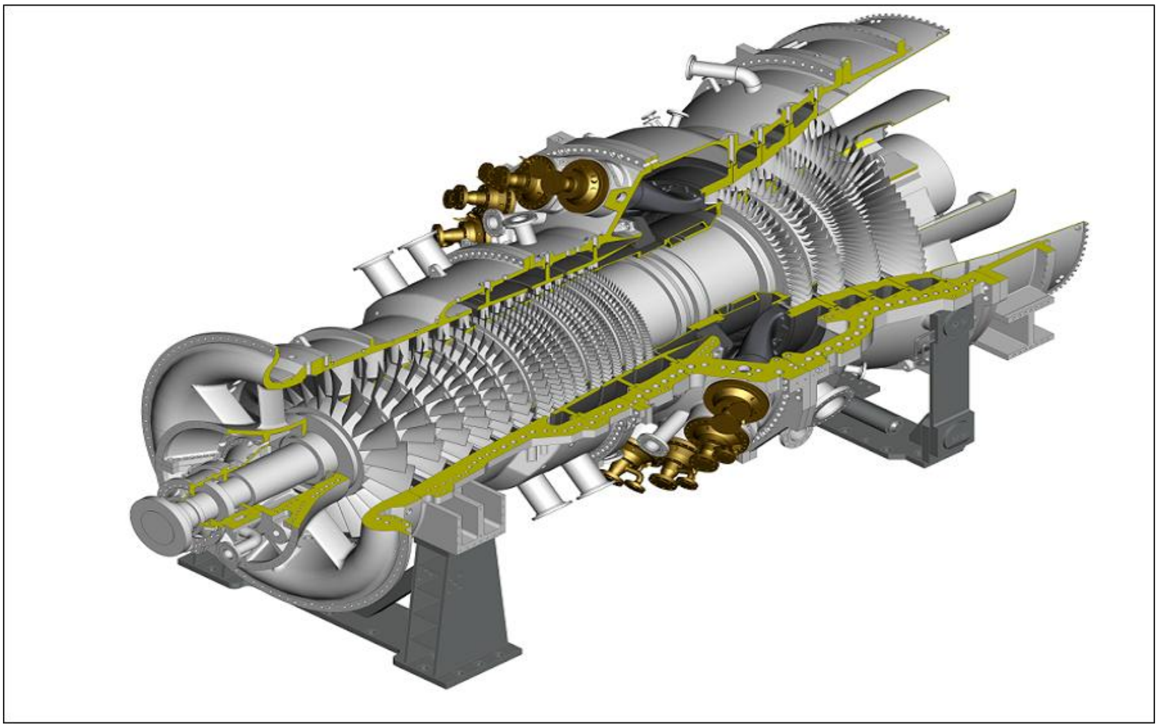

Figure 1: SGT6-5000F(3) Configured for IGCC Application

The SGT6-5000F(3) gas turbine configured with a syngas combustor coupled with IGCC technology makes it possible to use relatively low cost coal to produce ~230 MW of electrical power.

The relatively wide range of syngas fuel composition when compared to natural gas, presents challenges for the design and operation of the combustion system and gas turbine.

2 Syngas Combustion

The SGT6-5000F is modified with a 2-stage syngas combustor for IGCC applications. The 2-stage syngas combustor is based on the diffusion flame conventional combustor used extensively on the SGT6-3000E gas turbine. The two stage diffusion flame combustor displayed in Figure 2 is capable of operating on low calorific syngas fuel and natural gas.

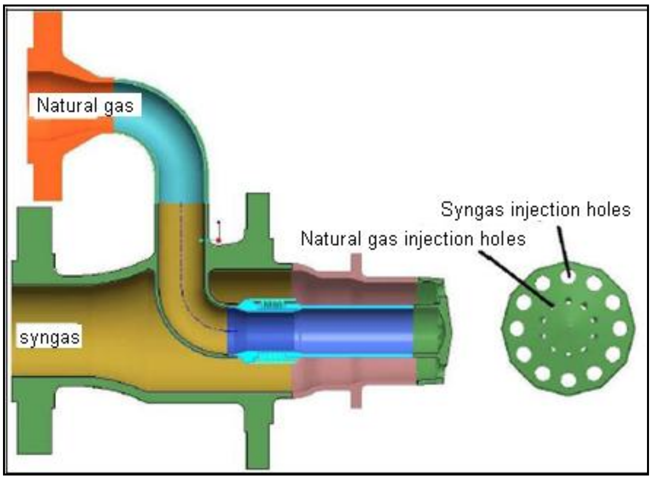

Figure 2: 2-stage Syngas Combustor Nozzle

2.1 Syngas Combustion Rig Testing

Syngas composition can vary significantly at IGCC plants depending on the coal feed and gasification process. The fuel composition, namely the hydrogen content, impacts flashback, emissions, and combustion dynamics, therefore it is imperative to test the performance of the syngas combustor with a range of hydrogen content in the fuel. The syngas combustion system was successfully tested in the single combustor, full pressure test rig exhibited in Figure 3.

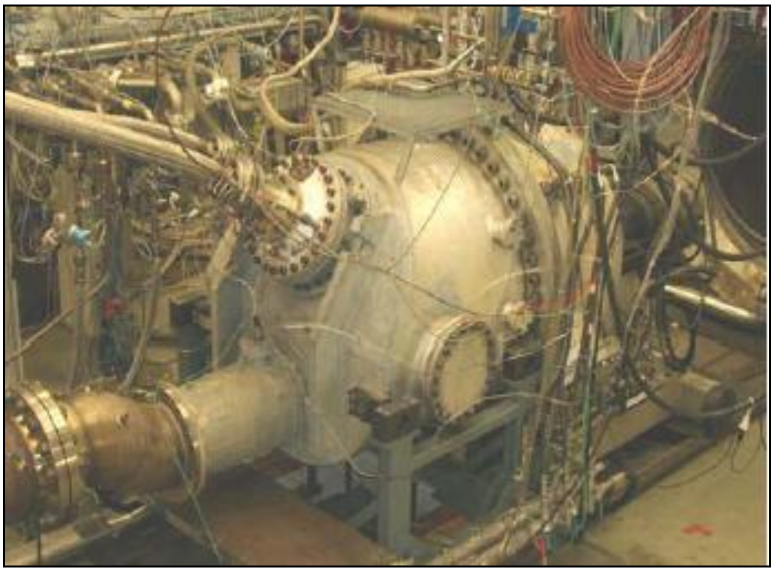

Figure 3: Single Combustor, Full Pressure Test Rig

The syngas fuel composition was varied per Table 1 during rig testing of the syngas combustor to establish the required dilution of syngas to achieve emissions targets and stable combustion.

Table 1: Syngas Composition Range (rig testing)

Test Rig Syngas Composition Range		
mol%	Min	max
H_2	11%	73%
CO	0%	46%
CH_4	0%	5%
CO_2	0%	14%
N_2	0%	60%

2.2 Emissions with Syngas Fuel

The syngas heating value increases as the hydrogen content increases resulting in an increase in stoichiometric flame temperature and a corresponding increase in NOx emissions. Although steam saturation proved to be more effective at reducing NOx emissions, N_2 is readily available from the syngas process and is used as the primary diluent. Typically there is a limit to the amount of N_2 diluent available though, and steam saturation may also be required to meet NOx emissions targets. The diffusion flame syngas combustor is able to achieve <15ppm NOx emissions at base load by reducing the stoichiometric flame temperature through N_2 dilution and/or steam saturation as displayed in Figure 4.

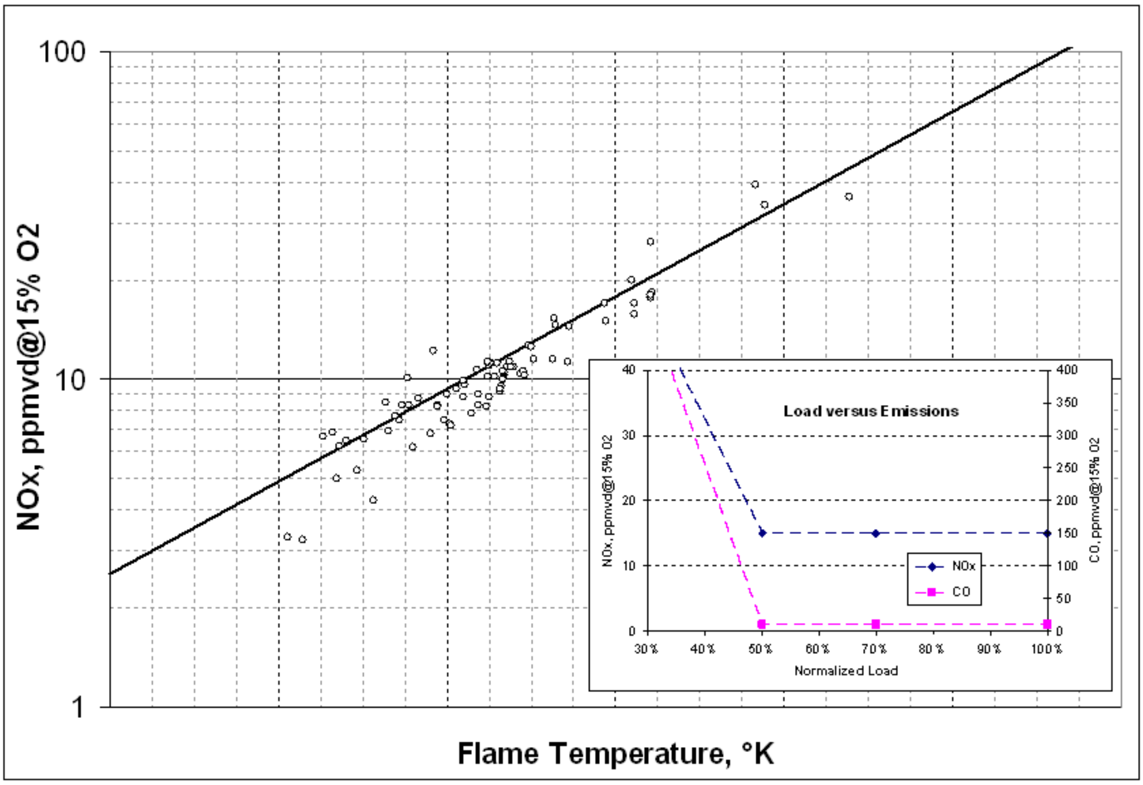

Figure 4: Stoichiometric Flame Temperature vs. NOx emissions

2.3 Combustion Dynamics with Syngas Fuel

Combustion dynamics levels during rig testing on syngas were relatively lower than typical combustion dynamics levels observed during natural gas operation. The combustion dynamics levels measured during syngas rig testing were <10 mbar as displayed in Figure 5, which is below any level of concern.

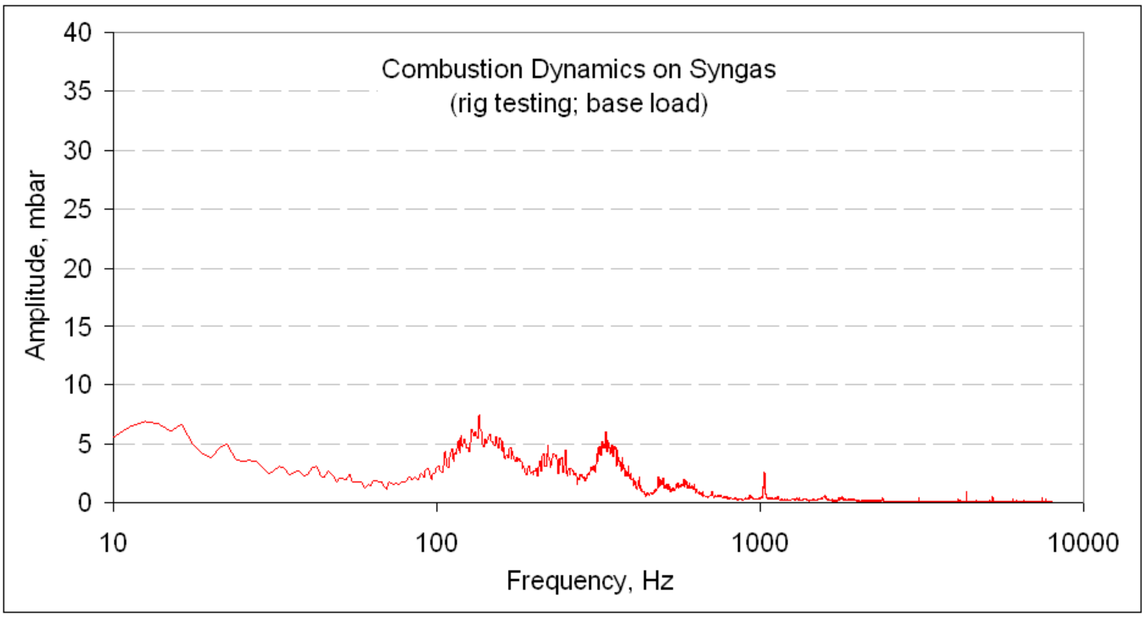

Figure 5: Syngas Combustion Dynamics

It is postulated that syngas combustion dynamics levels are lower than natural gas combustion dynamics levels because the syngas flame moves upstream relative to a natural gas flame where the flame is in a more stable position.

2.4 Flashback with Syngas Fuel

Combustion flame flashback is a primary design consideration especially when operating with syngas because the flame speed of hydrogen is roughly 10x that of natural gas. Laboratory tests were conducted to measure the influence on flame speed as the hydrogen content in syngas is varied as illustrated in Figure 6.

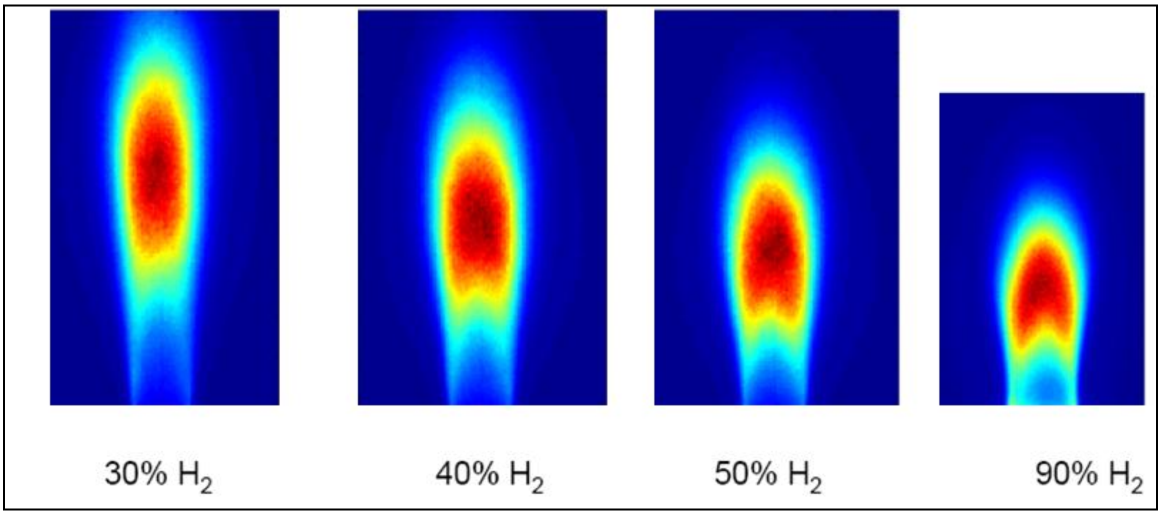

Figure 6: Flame Images with Varying Hydrogen Content

The flame becomes shorter as the hydrogen content increases, indicating an increasing turbulent flame speed. High flame speed increases the risk of the syngas flame propagating quickly to areas not designed for those temperatures, if there is not sufficient flashback margin in the combustor design. The diffusion flame syngas nozzles and combustor of the SGT6-5000F(3) demonstrated sufficient margin against flashback during rig testing.

The syngas combustion system was tested extensively in the rig and the design proved to have sufficient margin on flashback, combustor dynamics, and emissions. In addition to combustion, this relatively low energy fuel presents challenges with gas turbine operation.

3 Gas Turbine Operation

The SGT6-5000F(3) equipped with a syngas combustor is planned for IGCC applications where the syngas heating value ranges from 5,095 kJ/kg (2,190 Btu/lb) to 10,700 kJ/kg (4,329 Btu/lb). The syngas heating value entering the combustor is relatively low compared to natural gas (48,800 kJ/kg (20,980 Btu/lb)) therefore the syngas fuel mass flow required to obtain the same load on natural gas is ~10x as much. For example, at 15^{o}C (59^{o}F) ambient temperature the syngas fuel mass flow required to obtain 230 MW is ~115 kg/s (254 lb/s) while the natural gas fuel mass flow required to achieve this same load is ~12 kg/s (26 lb/s). The relatively high syngas fuel mass flow through the turbine increases compressor pressure ratio and changes component boundary conditions when compared to typical natural gas operation. The two primary considerations with the change in boundary conditions during syngas operation are compressor surge and turbine blade 4 flutter.

3.1 Turbine Blade Flutter

During syngas operation the SGT6-5000F(3) exhaust flow can exceed 550 kg/s (1213 lb/s), which is 11% greater than the typical exhaust flow during natural gas operation. This higher exhaust flow increases the risk of aerodynamically driven turbine blade 4 flutter. The row 4 turbine blade of the SGT6-5000F(3) displayed in Figure 7 was tested in the Berlin Test Facility in order to explore the limits of flutter, and it was found that the blade had adequate flutter margin.

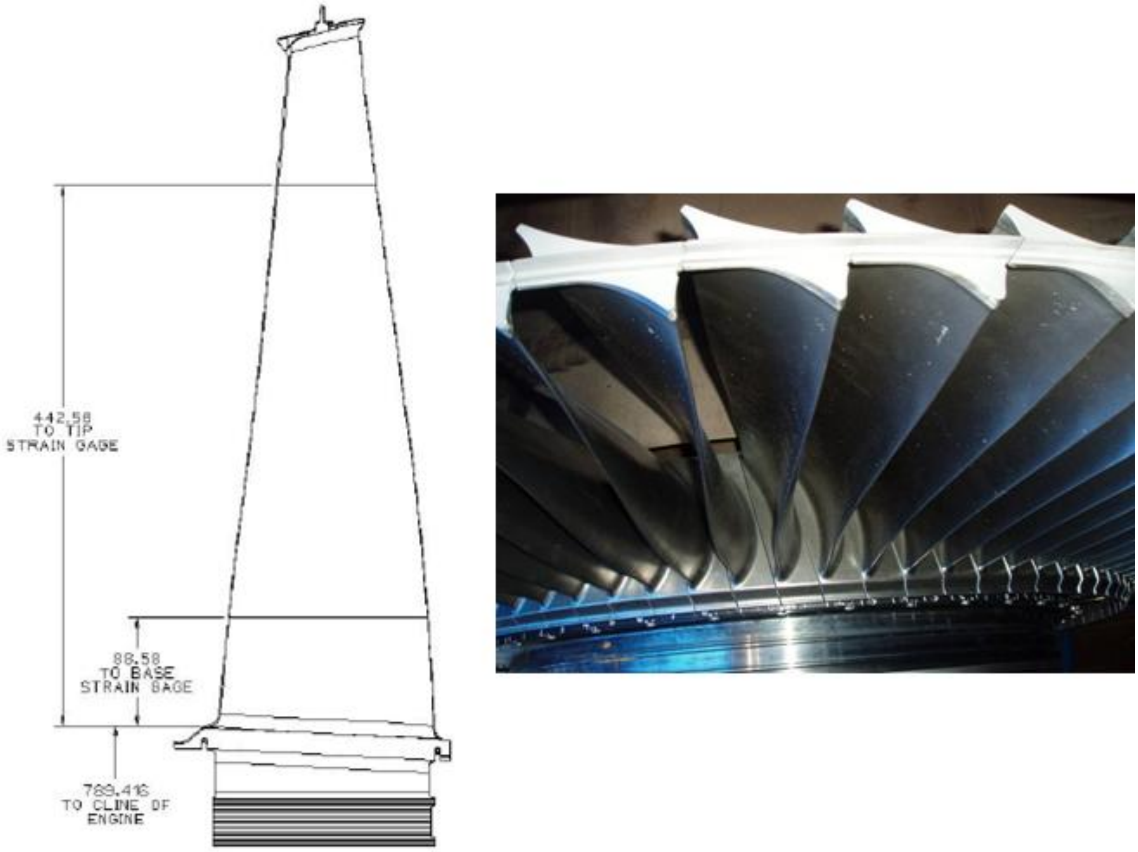

Figure 7: Row 4 Turbine Blade

3.2 Compressor Surge

The risk of compressor surge increases as the compressor operates at higher pressure ratios during syngas operation. The risk of surge in the SGT6-5000F(3) is mitigated by bleeding air off of the compressor in order to maintain a certain margin. The surge margin is defined in terms of pressure ratio as shown in Equation 1.

$$SurgeM\arg in(\%) = \left(\frac{PR_{surge}}{PR_{actual}} - 1 \right) * 100\% \qquad (1)$$

The actual pressure ratio (PR_{actual}) is the compressor exit pressure divided by the compressor inlet pressure, and the surge limit (PR_{surge}) is calculated and entered as a table in the control system logic. The gas turbine control system will calculate the surge margin and bleed air off of the compressor until the desired pressure ratio is obtained that provides adequate surge margin.

In many IGCC plants the gas turbine is integrated with the gasification process where the compressor exit air is used in the gasification of the coal feed stock. In these IGCC plants the compressor bleed air for surge prevention is utilized in the gasification process. In some instances the gas turbine is not integrated with the gasification process, and the air that is bled from the compressor for surge mitigation is utilized for other gas turbine operations such as compressor anti-icing or improving operational flexibility.

3.3 Recirculation of Compressor Exit Air

During syngas operation when compressor inlet temperature is less than ~25^{o}C the SGT6-5000F(3) operates at the gas turbine power limit of 235 MW. The control system prevents the gas turbine power from increasing above 235 MW by closing the inlet guide vanes to restrict the compressor inlet air mass flow. Instead of closing the inlet guide vanes to restrict gas turbine power, the compressor bleed air for surge prevention can be recirculated back to the compressor inlet for a certain range of ambient conditions, which will allow the inlet guide vanes to operate near the fully open design point where compressor efficiency is optimized.

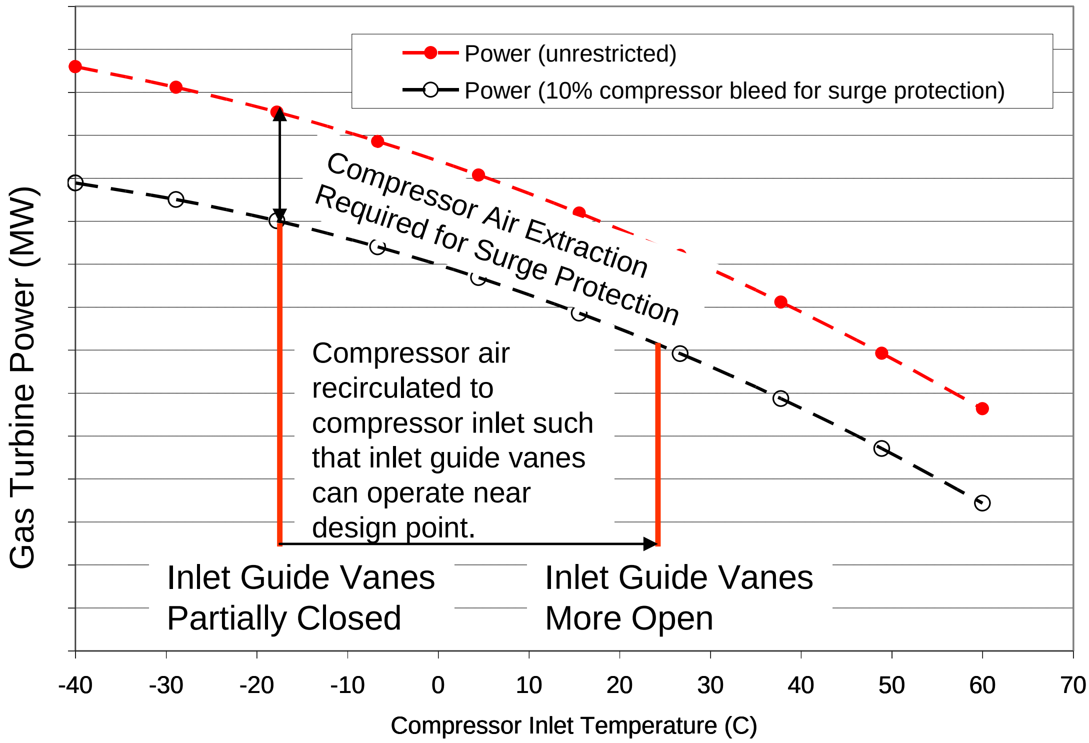

Figure 8: Recirculation of Compressor Extraction Air

3.4 Co-Fire Operation

Startup, acceleration, and loading to 30% gas turbine load are restricted to natural gas fuel. When gas turbine load is greater than 30%, the engine may operate on 100% natural gas, 100% syngas, or in co-fire mode as shown in Figure 9.

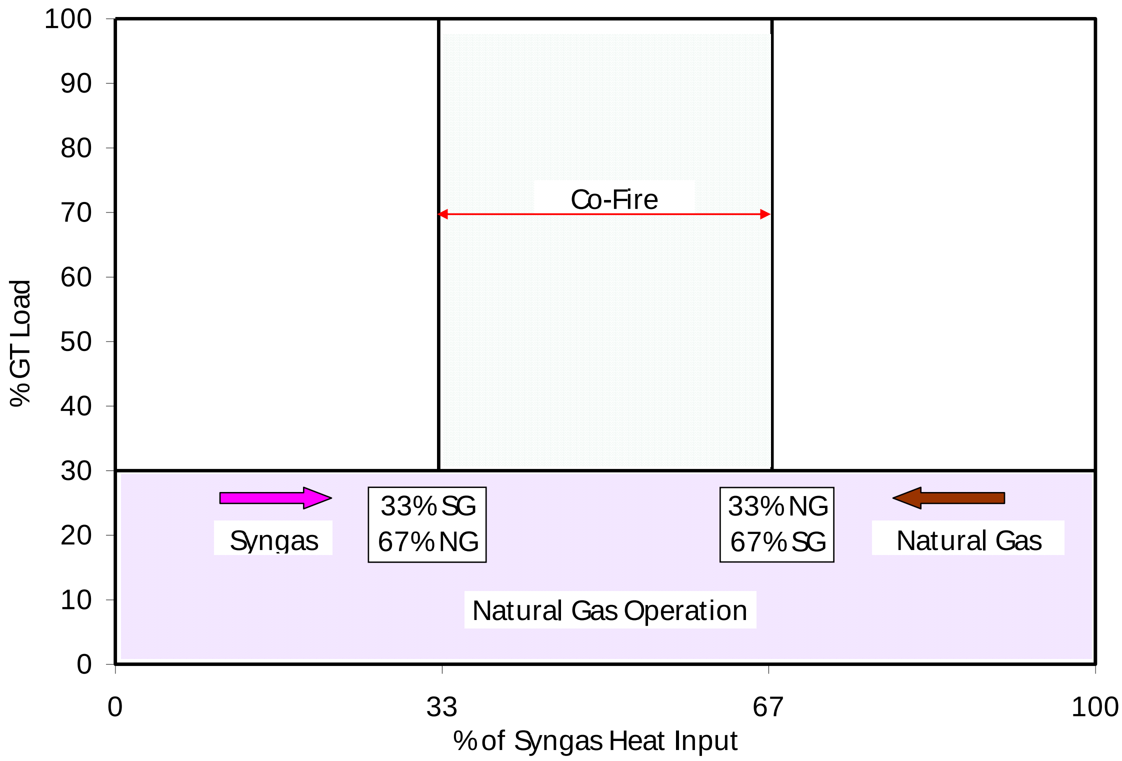

Figure 9: IGCC Operational Concept

Co-firing, when natural gas and syngas fuel are combusted simultaneously, provides operational flexibility in cases where syngas availability is insufficient and needs to be complimented. During co-fire operation the heat input from syngas is controlled via a Wobbe meter in order to maintain stability of the gas turbine. The heat input from syngas and natural gas is typically split in the 33% to 67% range, and when loading (or unloading) the gas turbine in co-fire mode, equal amounts of heat input from natural gas and syngas are increased (or decreased) to the combustor.

4 Summary

Extensive combustion rig testing on syngas fuel and years of IGCC experience have been implemented into the SGT6-5000F(3) gas turbine. This F-class gas turbine in IGCC applications will utilize low calorific syngas fuel to produce ~230 MW of reliable power. The first two SGT6-5000F(3) gas turbines for an IGCC application will ship from the factory in May 2012 and first fire on syngas fuel is planned for January 2014.