

## **INTRODUCING THE SGCC6-5000F 2x1 REFERENCE POWER BLOCK FOR IGCC APPLICATIONS**

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### **ABSTRACT**

Market pressures in the United States toward rising natural gas prices and the need for more environmental friendly generation of electricity have caused increasing customer interest in Integrated Gasification Combined Cycle (IGCC) Technology. These plants offer an option to traditional coal plants with key enhancements in the areas of performance as well as emissions. These technologies offer long term potential of carbon dioxide capture and sequestration as the push for virtually zero emissions continues.

In response to these market needs, Siemens Power Generation has developed a 2x1 (2-on-1) reference power block based on the utilization of our SGT6-5000F gas turbine which has undergone extensive verification for IGCC applications. This reference power block is known as the SGCC6-5000F 2x1 and the subject of this paper is to provide an overview of some of the key design features of this plant.

This nominal net 630 MW power block is equipped with two SGT6-5000F gas turbines and associated Totally Enclosed Water-to-Air Cooled (TEWAC) generators, two triple pressure reheat heat recovery steam generators, and a dual side exhaust SST6-5000 steam turbine with associated hydrogen-cooled generator. The power block has been developed and optimized to support all integration requirements of the ConocoPhillips E-gas™ coal gasification technology and supports operation on synthetic gas (“syngas”) with backup operation on natural gas.

The IGCC reference power block has been developed using the standard SCC6-5000F 2x1 natural gas turnkey reference power plant as the basis and maintains all of the benefits of performance, cost, and availability afforded by our reference power plant development programs.

## INTRODUCTION

Siemens experience with design and construction of combined cycle power plants in the United States dates back nearly four decades. The first generation of combined cycle plants were developed in the 1960's and utilized the W301 (a 30 MW) gas turbine. The second generation of combined cycle plants were introduced in the early 1970's marking the first development utilizing the W501B as the prime mover. The plant developed around this gas turbine was pre-engineered as a standardized combined cycle plant.

The Siemens 60 Hz combined cycle products developed utilizing the SGT6-5000F are based on the insight derived from these previous design efforts. The SCC6-5000F 2x1 combined cycle plant was designed to meet the base load, intermediate load and peak load requirements of utilities, independent power producers and merchant plant operators alike.[1] This combined cycle plant product was primarily developed to support natural gas firing of the gas turbines with option packages to support backup fuels (e.g. fuel oil). The plant design features a high degree of modularization, which reduces site-specific engineering, construction time and start-up/commissioning time. Modularizing the base designs and several of the most common major options maximizes possible replication from existing and proven plant designs in a typical project.

Siemens plant designs also include adaptability to a variety of construction management and scope of supply approaches. Drawing on our vast experience, Siemens is able to offer combined cycle plants as complete turnkey projects including detailed design, construction management, start-up and commissioning, training programs, and operations and maintenance services.

Combining our extensive combined cycle design experience with the application of the reliable and proven SGT6-5000F, Siemens is responding to North American customer demand for a competitive and attainable IGCC solution for new coal-based generation opportunities. Siemens has over 300,000 hours of successful gas turbine operating experience on low-BTU fuels including IGCC applications in the United States and Europe, and has supplied a range of products from gas turbines to compression solutions and plant controls for many of today's IGCC plants. [2]

The Siemens approach for development of a power block for IGCC applications is to apply the Siemens Reference Plant Design Philosophy that was utilized in the development of the 2x1 natural gas fired turnkey power plant based on the SGT6-5000F. Key elements of this approach are to understand the market needs, to identify combinations of power block equipment which satisfy the basic needs and to identify options which are required to satisfy expanded future market needs. This approach differs from traditional plant approach by building in the flexibility required to satisfy differing project requirements while obtaining advantages of replication. The approach permits modular design development to a detail beyond that practical for architect-engineer and other project developers.

The reference power plant philosophy results in fixed spatial configurations and establishes a firm basis for determining bulk material quantities and constructor scope definition. Pre-designed option modules provide means to accommodate varying site and project requirements with minimal impact to the base plant modules. The result is a design package of significant detail

that is highly repeatable from project to project while maintaining the flexibility necessary to meet customer needs.

Modularization and replication improve responsiveness to customer requests for proposals both in response time, cost, and in quality of information provided. The high level of detail available during the early development stage of the project provides an added degree of confidence in capital cost estimates, operation & maintenance cost estimates, and implementation schedules. The permitting process is also expedited due to the availability of firm design information early in the project. These factors ease concerns often expressed by lending institutions providing financing on independent power producer and co-generation projects thus helping to expedite financial closing.

In order to develop a reference power block for IGCC applications that in turn supports the overall objective of developing a cost and performance optimized total IGCC plant, it is critical to develop a system that takes full advantage of all integration opportunities between the gasification systems, the air separation unit, and the power block. In support of existing project opportunities, Siemens is working with ConocoPhillips; therefore, the reference power block supports all of the requirements of the E-Gas™ coal gasification process.

The base configuration of this reference power block directly supports the E-Gas™ technology and allows for the potential operation on various compositions of syngas produced from the various feedstocks supported by the E-Gas™ technology. The ConocoPhillips E-Gas™ Technology for Gasification has been utilized to process millions of tons of sub-bituminous and bituminous coal and petroleum coke. The oxygen blown, slurry fed gasifier has two stages of gasification and incorporates proprietary slag removal, char recycle and syngas cooling schemes. The gasification island design being incorporated in the 630 MW IGCC reference facility for the existing project opportunities is an incremental advancement over the Wabash River IGCC Facility design, operating since 1995 to improve plant efficiency and availability.

In addition, the power block supports the ability to incorporate selective catalytic reduction for NOx control as well as the ability to support (with some modification of the power block) carbon capture and sequestration modifications to the gasification island.

## **“DESIGN BASIS”**

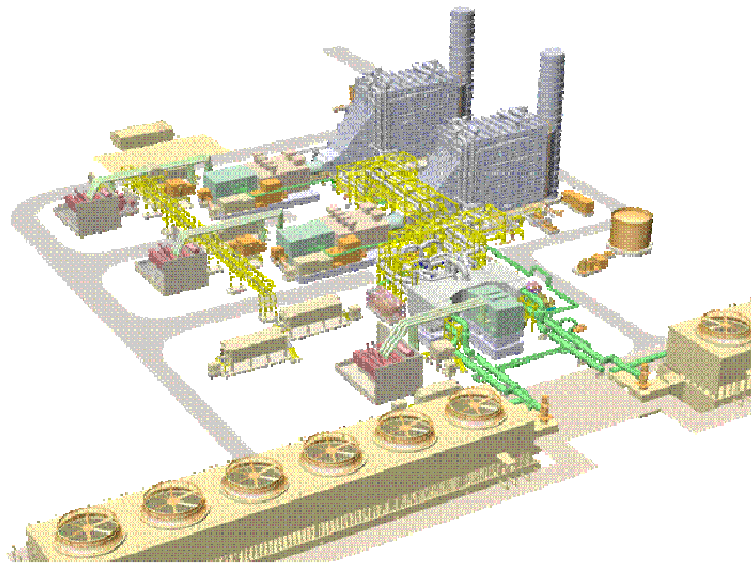
The power plant used as the baseline for the development of the IGCC power block is the SCC6-5000F 2x1 Reference Power Plant (Figure 1). It is a multi-shaft combined cycle plant, consisting of the following major equipment [1]:

- Two Siemens SGT6-5000F gas turbines (GTs) equipped with dry-low NOx combustion system and upstream inlet air evaporative coolers.
- Two Triple pressure reheat, Heat Recovery Steam Generators each with an HP once through evaporator system, IP and LP drum type evaporators, an SCR, and IP and LP rotor air coolers.

- One SST6-5000 two-case steam turbine with a reheat, opposed flow HP-IP element and double-flow LP element.
- Three (3) SGen6-1000A Air-Cooled Generators for the Gas Turbines and Steam Turbine.
- A steam surface condenser with a forced draft cooling tower for heat removal.

While operating on natural gas, this plant has an ISO rating of approximately 582 MW with an efficiency approaching 57%, with NO<sub>x</sub> emissions below 4 ppm @ 15%-Vol O<sub>2</sub> (with SCR). It is designed to operate across wide ambient temperature -5°F (-20.6°C) to 105°F (40.6°C) and barometric pressure from sea level to 3300 ft (1006 m) ranges. Necessary systems for 100% steam turbine bypass operation and fast start-up capabilities are also incorporated.

The Heat Recovery Steam Generator (HRSG) and balance of plant equipment are designed to operate at optimal conditions according to the gas turbine exhaust flow and temperature when firing natural gas. Operating the current gas turbine with syngas fuel (with natural gas as the backup fuel) will lead to changes in the exhaust conditions that will impact the performance of the bottoming cycle. In addition, how integration of the gasification island with the water-steam cycle of the power block is handled can have an impact, good or bad, on overall plant optimization. These potential sources of integration between the power block and the gasification island inclusive of the air separation unit (ASU) systems include fuel conditioning, air integration of gas turbine compressor air to air separation process, cooling of extraction air, and various low and high temperature heat recoveries from the gasification island processes. These impacts along with the performance of the IGCC power block are discussed in a later section of this paper.



**Figure 1. SCC6-5000F 2x1 Natural Gas Combined Cycle Reference Power Plant**

As the reference power block for IGCC applications draws heavily from the design of the natural gas fired “sister” unit, much of the design basis is similar if not identical. The performance of the power block has been optimized for ISO conditions with ensured capability of operation across the previously mentioned ambient envelope. The natural gas plant was developed with the capability for the inclusion of optional emissions reduction systems (NO<sub>x</sub> SCR and CO catalyst systems). Application of these systems are not without gasification island impacts as operation and maintenance (O&M) concerns dictate the level of sulfur removal required from the syngas to avoid ammonia sulfate formations in the HRSG with the application of an SCR. Furthermore, the natural gas plant has been developed utilizing a standard set of civil and environmental criteria (e.g. seismic loading for all equipment and structures shall be designed to resist seismic according to IBC2003, Category III Structure) which serve as a basis for modification to address customer specific requirements.

The remainder of this paper discusses the differences in design to the major power block systems and equipment that resulted from the evolution of the SCC6-5000F 2x1 plant for natural gas operation to the SGCC6-5000F 2x1 power block for syngas operation in IGCC applications. Inclusive in this will be discussions in differences in scope terminology definitions.

## **POWER BLOCK DEFINITION**

For natural gas based combined cycle applications Siemens offers a variety of scope of supply options:

- Gas turbine generator equipment package – SGT6-PAC 5000F Power Plant
- Combined cycle major equipment package – SCC6-5000F Power Island
- Combined cycle complete turnkey power plant – SCC6-5000F Turnkey Power Plant

For IGCC applications, Siemens can supply similar build ups in scope up to and including what is referred to in this paper as the SGCC6-5000F 2x1 power block. In this turnkey scope of supply, Siemens supplies all of the power plant equipment that comprises the power block portion of the total IGCC plant in a turnkey supply including all engineering, procurement, and construction. Where appropriate, Siemens will partner on a consortium basis with others such as ConocoPhillips and Fluor on a project specific basis to build the entire IGCC plant as a turnkey scope of supply. The equipment provided by Siemens as part of the turnkey reference IGCC power block is shown below in the general arrangement (Figure 2). The power block includes the gas turbines and generators, the steam turbine and generator, power electrics, HRSGs, condenser, cooling tower, major pumps, bypass systems, and the cooling water systems all in a turnkey configuration (Figure 2 also details the legend for the general arrangement). In addition, as part of this turnkey configuration Siemens offers the SPPA-T3000 control system which is capable of addressing all of the control requirements of the power block and can be extended for application to the entire IGCC plant as well.

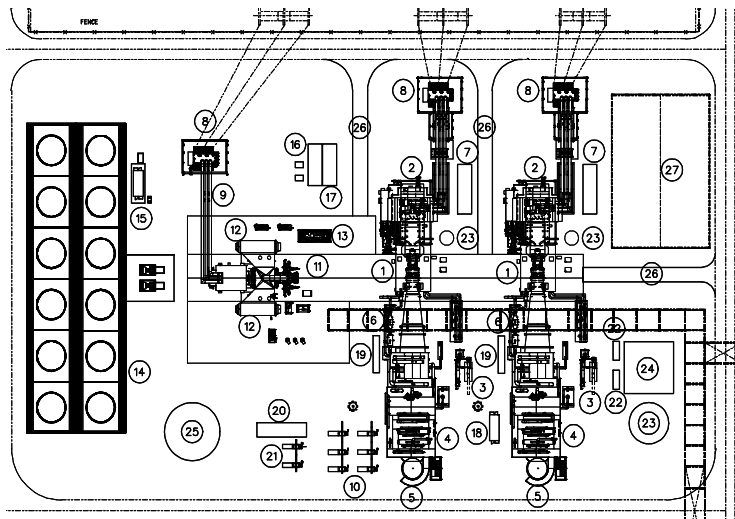
## NOTES

1. THE EQUIPMENT SHOWN IS REPRESENTATIVE INFORMATION. THIS DESIGN IS SUBJECT TO CHANGE AT THE DISCRETION OF SIEMENS.
2. ROTOR AIR COOLER (ITEM 6) CANNOT BE MOVED DUE TO PRE-ENGINEERED PIPING. MOVING THE UNIT WILL IMPACT COOLER PIPING STRESSES AND LOADS.
3. REFERENCE DRAWING GA05010103 FOR THERMAL ISLAND EQUIPMENT DIMENSIONS AND IDENTIFICATION.

## LEGEND

- 1 GAS TURBINE ENCLOSURE
- 2 TURBINE AIR INLET FILTER
- 3 FUEL GAS PREHEATER
- 4 HEAT RECOVERY STEAM GENERATOR
- 5 HRSG STACK
- 6 ROTOR AIR COOLER
- 7 MV SWITCHGEAR
- 8 GENERATOR STEP UP TRANSFORMER
- 9 ISOPHASE BUS DUCT
- 10 BOILER FEED WATER PUMPS
- 11 STEAM TURBINE
- 12 SURFACE CONDENSER
- 13 LUBE OIL SKID
- 14 COOLING TOWER
- 15 COOLING TOWER POWER CONTROL CENTER
- 16 STEAM TURBINE POWER CONTROL CENTER
- 17 BALANCE OF PLANT POWER CONTROL CENTER
- 18 HRSG POWER CONTROL CENTER
- 19 AIR EXTRACTION COOLERS
- 20 FEEDWATER STORAGE TANK
- 21 FEEDWATER BOOSTER PUMPS
- 22 SUBCOOLERS
- 23 NITROGEN STORAGE TANK
- 24 SYNGAS BOP SYSTEM
- 25 RAW WATER STORAGE TANK
- 26 ROADS
- 27 MAINTENANCE BUILDING (BY OTHERS)

CONCEPTUAL



**Figure 2. SGCC6-5000F 2x1 Reference Power Block for IGCC Applications  
General Arrangement**

Beyond the typical combined cycle scope of supply, for IGCC applications, a portion of the fuel conditioning scope (e.g. syngas, water/steam for gasification island cooling, dilution nitrogen, air extraction) is included in the power block scope of supply. A reference interface point is established within the total plant defining the split between the consortium members. These piping interfaces exist near the lower right hand corner of the general arrangement as shown. Nevertheless, Siemens has developed a scope split with our partners on our existing projects that allow each partner to implement its scope and manage its risks while being transparent to the customer. The customer can view the supply of the plant from the consortium as one total facility from one supplier.

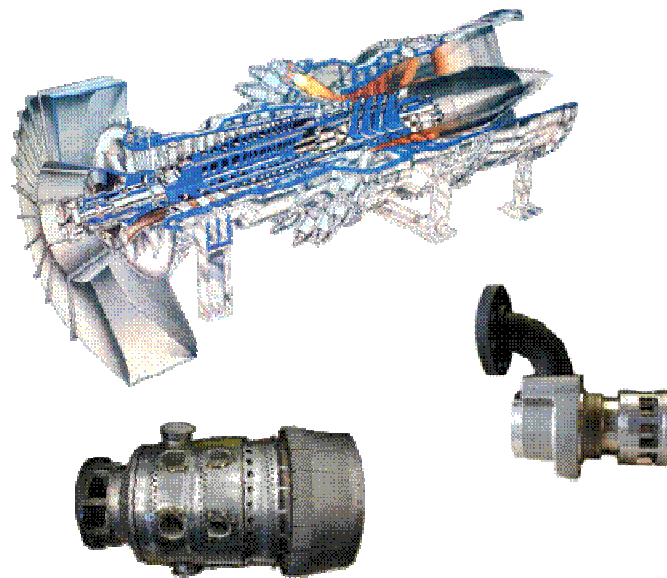
## GAS TURBINE

The gas turbine implemented in the development of the SGCC6-5000F 2x1 power block for IGCC applications is the SGT6-5000F (Figure 3). This gas turbine is the most widely deployed model in the 60 Hz Siemens heavy duty gas turbine product line with more than 190 units operating in peaking, intermediate and continuous duty applications. Several advancements to this gas turbine model have increased its power, efficiency, and reliability while decreasing its emissions and life cycle costs. Siemens believes the SGT6-5000F has the attributes required to be an excellent platform for integration into an advanced IGCC plant.

The SGT6-5000F IGCC engineering program, which started in 2004, has focused on evaluating the standard SGT6-5000F used for natural gas service for IGCC applications. This program included evaluations of the gas turbine mechanical systems and development of an IGCC combustion system capable of operation with natural gas, syngas, and hydrogen based fuels. In

addition to the combustion of syngas with low emissions, Siemens also evaluated the effects from the increased fuel flow and the increased output of the gas turbine when operating on syngas. The ISO rating of the SGT6-5000F operating on syngas with the previously mentioned combustion system, is 232 MW, a 19.3% increase over its rating on natural gas, using a Dry Low NO<sub>x</sub> (DLN) combustion system.

The analysis and verification of existing and redesigned engine components was done for a potential worst case scenario, for each individual component, to ensure that all design limits and criteria would be satisfied for IGCC applications. Turbine analysis covered aerodynamic, mechanical, heat transfer and cooling aspects on the turbine airfoils, rotor and disc cavities. Aerodynamic analysis carried out on the turbine showed that the increased flow conditions were well within acceptable limits.



**Figure 3. SGT6-5000F Gas Turbine**

Syngas operation has a very significant impact not only on the turbine and the downstream equipment, but also on the gas turbine compressor as its surge margin is reduced, due to the increased operating pressure ratio, resulting from the increased mass flow through the turbine. Detailed compressor analysis concluded that adequate compressor surge margin could be maintained without first stage turbine vane re-stagger.

The only SGT6-5000F gas turbine components requiring modification were the combustor baskets and fuel nozzles (Figure 3). In addition to the gas turbine longitudinal, minor modification to some auxiliary systems (Figure 4) and controls were also required. [2]

Fuel type and gasifier operation mode generally have only a modest impact on the content of the syngas delivered to the power block. Since the syngas is further diluted to meet combustor inlet requirements, the gas turbine is positioned to operate over a wide range of fuel (feedstock) variability. The fuel handling systems used to moisturize and dilute fuel from the gasifier island have been designed to operate over the full range of expected ambient and operating conditions.

The syngas combustion system for the SGT6-5000F is based on the successful operation of the combustion system used on two Siemens W501D5 gas turbines at the DOW, LGTI IGCC Project between 1987 and 1995. It was developed to operate with syngas as the primary fuel from 30% load to maximum rated power, and natural gas as the secondary fuel. A NO<sub>x</sub> emission target of ≤15 ppm with low CO levels was set for syngas operation, using a combination of fuel moisturization and N<sub>2</sub> dilution. For natural gas operation, the target was set at ≤25 ppm NO<sub>x</sub> using steam as a diluent. The combustion tests included a wide range of syngas compositions expected from a number of existing and future gasifiers operating with a range of feedstock from coal to petcoke.

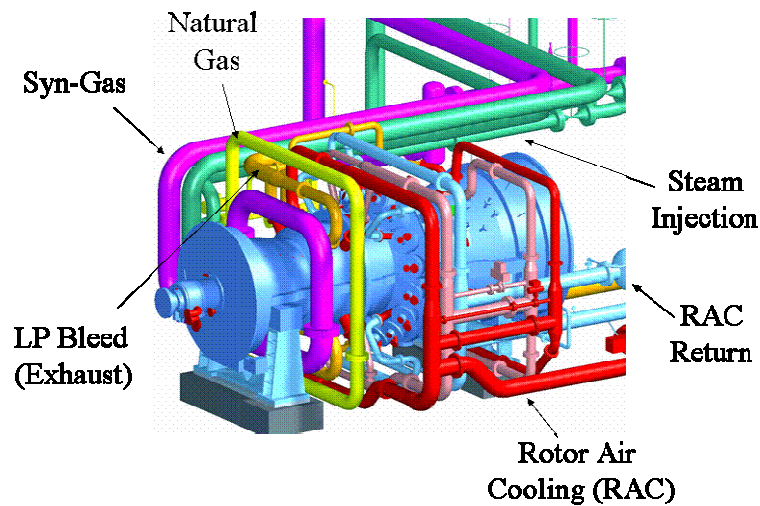
The combustion system testing was completed successfully in early 2005 and all the emissions and operational targets were demonstrated. Stable combustion was achieved on both the syngas and natural gas fuels. Syngas to natural gas transfers, and vice versa, at base load were achieved with stable combustion. Syngas/natural gas co-firing at base load and 30% load was also achieved with stable combustion. Ambient temperature variation was determined to have a minimal effect on NO<sub>x</sub> and CO emissions. Combustion dynamics and combustor and transition liner metal temperatures were well within design limits for all tests.

Extracting air from the gas turbine during operation to supplement the air supply of the ASU's main air compressors provides the opportunity to maximize the overall plant output with minimal effect on plant heat rate. For a typical nominal 630 MW IGCC plant, optimizing air side integration for power can lead to a 5% to 10% increase in net plant output with a minimal impact on plant net heat rate. Because more fuel is required to supply the gas turbine energy for the air extraction, more steam is raised in the HRSG and in the syngas cooler and sent to the steam turbine; thereby, increasing the output of the steam turbine. At the same time, the power consumption from the ASU's main air compressor drops significantly.

Based on past IGCC experience with Siemens gas turbines providing anywhere from zero to 100% of the ASU's air needs, Siemens has limited the range of air side integration from 0% to 50%. Limiting the range of integration provides the best balance between maximizing plant output and heat rate while maintain a level of availability and reliability that plant owners require.

The IGCC version of the SGT6-5000F supports the normal ambient operating range of ambient temperature from -5°F (-20.6°C) to 105°F (40.6°C) and of barometric pressure from sea level to 3300 ft (1006 m) altitude. Because of the increased mass flow through the turbine, the gas turbine output approaches the maximum capability of the turbine under most ambient temperatures. At ISO conditions, the estimated gas turbine output of the SGT6-5000F is 232 MW in IGCC applications. The normal starting time from start initiation to baseload is less than 30 minutes on secondary (natural gas) fuel. In an IGCC power block application, the gas turbines would be started on natural gas with transfer to syngas at or near 30% GT load. The reliability, availability and maintainability (RAM) targets are expected to be the same as for a standard natural gas-fired SGT6-5000F. These would directly support the objective of maintaining the same RAM targets in the turnkey power block for IGCC that exist for the natural gas plant. No changes are expected in the combustion system inspection, turbine hot gas path inspection and major overhaul intervals because of operation on syngas.





**Figure 4. SGT6-5000F Gas Turbine Auxiliary Piping**

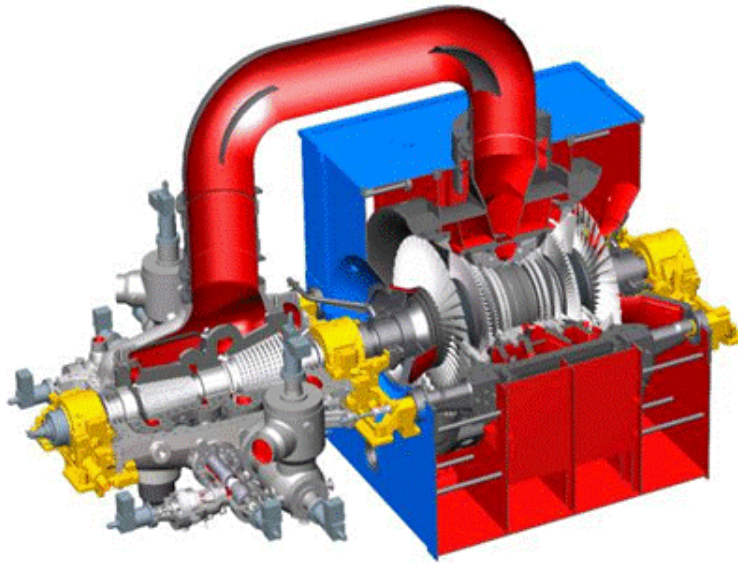
## STEAM TURBINE AND CONDENSER

### Steam Turbine

As mentioned previously, the steam turbine included in the natural gas combined cycle reference plant SCC6-5000F is the Siemens SST6-5000 (Figure 5). The steam turbine product applicable to the IGCC power block remains in the SST6-5000 class but is of a slightly larger size due to the increase in additional steam volume associated with integration to the gasification island cooling processes. The high temperature heat recovery process associated with syngas cooling produces a quantity of high pressure steam that is on the same order of magnitude of that produced via exhaust energy heat recovery. Each section of the steam turbine must be evaluated for the ability to accommodate this steam. This has led to an increased size of the combined HP/IP section as well as an increase in the exhaust area of the LP turbine.

This steam turbine has one opposed-flow combined high pressure/intermediate pressure (HP/IP) element and one double-flow low-pressure (LP) element. All components are packaged modules. The steam turbines are a tandem compound design and have individual shafts which are rigidly coupled.

The HP/IP turbine has an opposed-flow design with high and intermediate-pressure blading. The blading in this turbine is fully 3-dimensional high performance variable reaction (3DV™) blading with integral shrouds for high efficiency. This turbine has a horizontally split inner and outer casing.



**Figure 5. SST6-5000 Steam Turbine**

Steam of the HP section is exhausted vertically downwards through a single exhaust nozzle at the front end of the HP/IP turbine. A flanged joint is provided to connect the cold reheat line. IP steam is exhausted vertically upwards through a single exhaust nozzle at the generator end of the HP/IP-turbine. A flanged joint is provided for connecting the crossover pipe which carries the steam to the LP turbine.

The low pressure (LP) turbine consist of a double-flow unit with a horizontally split casing, exhausting on both sides into the condenser for the dual side exhaust condenser configuration.

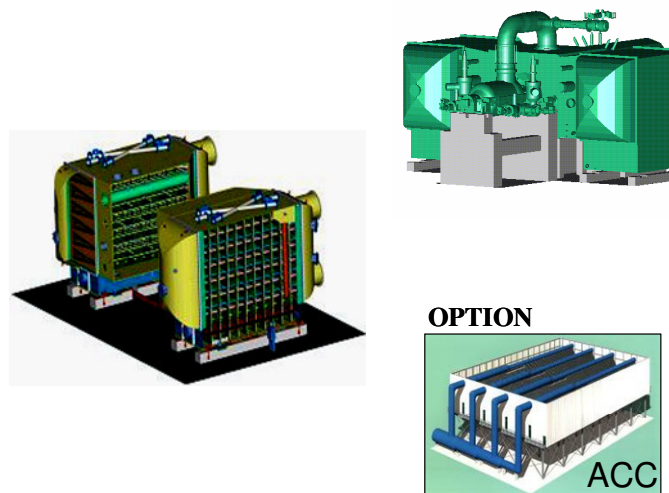
A top-mounted crossover pipe connects the HP/IP cylinder to the LP cylinder. A flow guide, or rotor deflector, is located at the LP inlet zone to minimize losses by optimally directing the inlet steam in the axial direction. Steam leaving the last row blade flows through an exhaust diffuser. The exhaust diffuser is designed with 3-D computational fluid dynamics in order to minimize exhaust losses. The diffuser converts exhaust steam velocity into pressure as the steam flows into a rectangular cross-section at the condenser inlet.

### **Condenser**

The condensing system employed in both the natural gas fired plant as well as the IGCC syngas power block is a water-cooled condenser with a forced-draft cooling tower. The main condenser (Figure 6) is part of the circulating water system and collects and condenses exhaust steam from the low pressure (LP) turbine, steam from the turbine bypass stations, and accepts condensate from locations such as drains, vents and steam seals.

In the natural gas fired plant SCC6-5000F 2x1, the heat rejection system (condenser and cooling tower) is sized to accommodate only steam produced via heat transfer with the exhaust energy from the gas turbine. In the power block for IGCC applications, there is an additional volume of

steam which is produced in the gasification island. The condenser and cooling tower have been increased in size to accommodate these heat rejection requirements. This is especially significant with respect to the steam turbine bypass systems which have been designed to accommodate full bypass of the steam turbine while receiving maximum steam flow rates from the gasification processes. The cooling tower accommodates the heat rejection for the power block only (cooling of the air separation systems in the gasification plant require a separate heat rejection system). It is sized accordingly inclusive of any additional energy delivered to the water steam cycle through the power block-gasification island interfaces.



**Figure 6. Water Cooled Condenser**

A generic description of the water-cooled condenser for either the natural gas fired reference plant or the syngas fired IGCC power block follows. An air-cooled condenser option is currently under development for the reference IGCC power block and is not discussed in this paper.

Circulating water flows through the condenser section(s) in two passes. The inlet water flows in one direction through the condenser tubes via the inlet nozzle on the inlet water box. The circulating water flow direction is reversed in the return water box, flows in the opposite direction through the condenser tubes and exits the water box via the outlet nozzle. The inside surfaces of the circulating water boxes are coated for protection against corrosion.

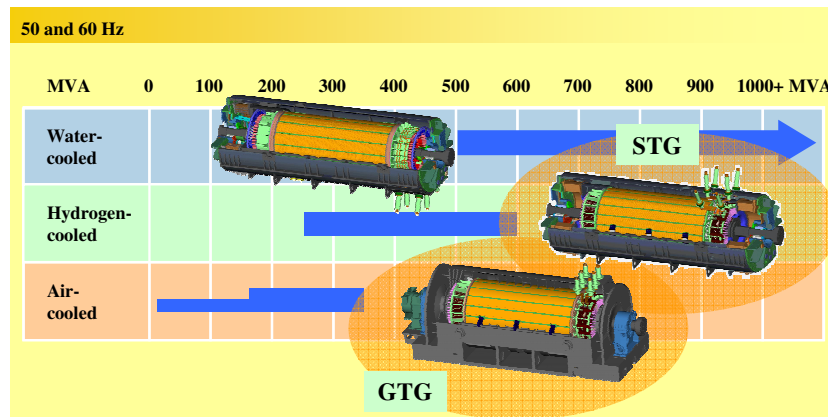
This condenser consists of two separate shell and tube sections, with non-divided water boxes, located along each side of the LP turbine axis. Steam discharged radially from the last stage of the LP turbine enters the condensing area of each section through the condenser neck oriented horizontal and perpendicular to the LP turbine shaft. This two-shell design makes it possible to shut down one half (one shell) of the circulating water system without interrupting condenser operation at reduced loads.

The steam inlet to the condenser is coordinated with the turbine exhaust and produces minimum exhaust losses. For the dual side exhaust turbine, the condenser neck is welded to the steam turbine such that the outer casing of the LP turbine is supported by the condenser.

## GENERATORS

The generators applied in SCC6-5000F 2x1 are of a similar type for both the gas turbines and the steam turbine. The base generator is a totally enclosed water-to-air-cooled (TEWAC) design with brushless excitation. The designation of this generator is the SGen6-1000A. The TEWAC generators with brushless excitation are of a low maintenance design. The TEWAC generators are shipped fully assembled (without coolers installed) to the site to facilitate easy erection.

As previously discussed, the reference power block for IGCC applications was developed using the natural gas plant design as the starting point. As such, the generators for the gas turbines remain the high efficiency and economical air-cooled type. However, as the level of water steam cycle integration was increased for higher performance, the steam cycle output increased well beyond the level from that of the natural gas fired plant. The increase in output is primarily associated with the high pressure steam generated in the syngas cooling process of the gasification island. This coupled with the fact that the output of the plant is more “levelized” (due to the performance characteristic of the gas turbine and the ability to recover the exhaust energy) as compared to a natural gas only plant led to a re-evaluation of the generator selection for the steam turbine. The generators selected for the IGCC application are shown in Figure 7. In addition, this figure demonstrates the change in frame type required associated with an increase in output at above nominally 300 MVA.



**Figure 7. GT and ST Generators**

The hydrogen-cooled generator selected for the steam turbine in the IGCC power block is from the Siemens modular product line. The generator designation is SGen6-2000H. The modular design approach utilizes common design features that benefits from proven standard designs which are quite cost effective. Utilizing a generator from a larger fleet of machines with the same basic designs affords the benefit of more field experience, increased service capabilities, and

assured manufacturing quality due to the application of standard processes and common tools. The hydrogen cooled generator is a high efficiency generator design that provides lower initial and operating costs to the customer. Some of the features enabling this high efficiency include low loss core components, optimized rotor windings, and low loss hydrogen blowers. [2]

## **WATER/STEAM CYCLE**

In a typical natural gas-fired combined cycle power plant, the HRSG design is thermodynamically optimized in support of a single operating point. This optimization is also mainly developed in support of maximizing the energy recovery from the gas turbine into the steam bottoming cycle. The optimization is typically represented by the average ambient day associated with the site. The goal is to maximize the plant thermal efficiency for the unit's average operating condition. The HRSG design is then enveloped for all other operating modes (e.g. ambient extremes or GT part load operation) to ensure feasibility of operation.

The optimization process is essentially the same for a HRSG developed for IGCC applications. The HRSG system is thermally optimized with consideration for all of the process integrations to the gasification island. These include but are not limited to superheat of the saturated steam received from the syngas cooling process in the gasification island as well as low temperature heat recovery from the syngas by heating of condensate or boiler feed water. The HRSG design is then enveloped for all other operating modes, including operation of the combined cycle on natural gas when the gasification island is off-line. This includes supporting the various start-up and shut-down scenarios as well as extended operation in 100% steam turbine bypass mode with the gasification island in-service.

In addition to the HRSG system, all other water-steam cycle equipment is optimized and sized to support a "heat balance" including all process integrations to the gasification island. Some of the systems/equipment that typically grow in size include major pumps, bypass systems, cooling water systems, and water treatment systems.

Included in the design of the power block is the syngas fuel conditioning system. This system is mentioned as part of the water-steam cycle because much of this fuel conditioning system was developed in response to performance optimization of the bottoming cycle as part of this reference power block. The fuel system as part of the overall water/steam cycle (and power block) addresses all of the requirements of the combustion system. These include but are not limited to heating of the syngas or backup natural gas with boiler feed water, dilution of the fuel with nitrogen from the air separation process, saturation of the syngas with water, measurement of the fuel heating value with some form of mass spectrometry, providing steam for the natural gas operation of the combustion system, and cooling of the extraction air from the gas turbine compressor prior to delivery to the air separation process as part of the gasification island. Of course, many of the features of the power block water/steam cycle have been incorporated to address the various aspects of integration within the larger IGCC plant. The next section of this paper discusses these integrations.

## PLANT INTEGRATION

A power block designed to operate on syngas will typically have several integration points with the gasifier and ASU islands. The following are the components that are interconnected and have process lines included in the power block scope of supply:

- Syngas:

The syngas from the gasification island is clean and undiluted. The power block systems must blend nitrogen and/or add moisture to condition the fuel to the required heating value for clean combustion.

- Nitrogen:

The nitrogen used in the fuel conditioning system comes from the air separation process in the gasification island. This nitrogen is interfaced to the power block at the required pressure for dilution of syngas prior to combustion.

- Air Extraction to ASU:

Part of the air used by the ASU to generate the oxygen can be extracted from the compressor of the gas turbine, reducing the auxiliary load consumed by the ASU's main air compressor.

- Air Extraction Cooling Systems:

Any air extracted from the GT compressor must be cooled prior to delivery to the ASU. This heat recovery can be used to produce saturated steam to improve the performance of the bottoming cycle.

- Condensate Preheating:

Gasification island processes (e.g. sulfur removal) may have some low level heat rejection requirements. This low level heat rejection can be used for preheating of condensate prior to delivery to the HRSG systems.

- Syngas Cooler:

High temperature heat recovery in the cooling process leads to high volume of steam production. This ultimately is the driver for many of the power block design modifications required to the natural gas plant basis.

- Syngas Saturator:

The heat source for the water delivered to the saturator can come from a variety of sources. Heated boiler feedwater or water that has been delivered to the gasification island for energy recovery could be used.

System designs have been implemented to address all of the previously mentioned interface requirements. In terms of power block impact; this primarily is addressed through the sizing of main piping in support of the fluid interfaced between the power block and the gasification island. One item of significance not specifically covered by this paper is the impact of the various feedstocks to the gasification island on the sizing of the main interface piping. Currently, the power block design is being approached with the objective of developing a set of modular designs that can accommodate a range of feedstocks for any given project.

## **PERFORMANCE AND EMISSIONS**

The goal and objective of the development of the reference power block for IGCC applications was to develop a design that provides the best combination of performance, operating flexibility and cost effectiveness. The first IGCC power block developed by Siemens Power Generation has been optimized for the ConocoPhillips E-Gas™ process and can deliver approximately 630 MW net at a net plant efficiency of over 40.5% on an HHV basis for bituminous coals. In addition, in order to address the permitting of this power block into “coal friendly” applications, the power block is capable of supporting emissions of less than or equal to 15 ppm NO<sub>x</sub> with low CO on syngas without the need for SCR or CO catalyst systems. If required, application of these emissions reduction systems (with a modification of the sulfur removal technology in the gasification island) can reduce the NO<sub>x</sub> levels to below 4ppm with low CO levels.

## **SUMMARY AND CONCLUSIONS**

The SGCC6-5000F 2x1 power block for IGCC applications represents a logical extension of the development completed on the natural gas combined cycle reference plant SCC6-5000F 2x1. It will help improve the overall IGCC plant performance and economics through better optimization with the gasification island. The heart of the power block is the SGT6-5000F which requires only the addition of a syngas combustion system along with other minor changes. Many of the power block systems and equipment remain unchanged in IGCC design but merely require a resizing in response to the impact of integration on the water steam cycle. The most notable modification in the power block is the switch from the air-cooled SGen6-1000A generator to the hydrogen-cooled SGen6-2000H generator for the steam turbine due to the increase power block output.

The SGCC6-5000F 2x1 power block is the basis of an IGCC plant design that is well suited to meet the current and future needs of the IGCC plant customers who are seeking a competitive coal based, 600 MW class power generation solution in the 60 Hz market.

## **PERMISSION FOR USE**

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