

INSTITUTION OF MECHANICAL ENGINEERS HONG KONG BRANCH
THE HONG KONG INSTITUTION OF ENGINEERS GAS AND ENERGY DIVISION
INSTITUTION OF GAS ENGINEERS & MANAGERS FAR EAST DISTRICT SECTION
JOINT DELEGATION TO SHANGHAI IN 2019
TECHNICAL VISIT TO SHANGHAI ELECTRIC GROUP



Combined cycle (CCGT), comprises gas turbine (GT), steam turbine (ST), heat recovery steam generator (HRSG) and their auxiliaries, combines Brayton cycle and Rankine cycle for GT and ST respectively to convert chemical energy in fuel, either gas or oil, into electricity in efficiency as high as 55 %. It is a major use of natural gas and effective way of satisfying the demands of electricity in a less polluting and high efficiency way. Headquarters in the Shanghai municipal, Shanghai Electric Group (SEG) is the key CCGT total solution provider in China by means of designing, manufacturing, supplying and supporting CCGT units under one single roof. Privileged members of Institution of Mechanical Engineers Hong Kong Branch (IMEchE-HKB), The Hong Kong Institution of Engineers Gas and Energy Division (HKIE-G&E) and Institution of Gas Engineers & Managers Far East District Section (IGEM-FEDS) were able to visit SEG full day on 4/6/2019 and appreciate its design, manufacturing and support capabilities for CCGT.

Gas Turbine Journey with Siemens

Gas turbine (GT) was invented in Europe and now Europe, Japan and the U.S. have led the gas turbine industry over the past decades. On the other hand, China embarked the gas turbine odyssey after the People's Republic was found in 1949, and the champion was the nowadays SEG, which is now an integrated power engineering solution provider, offering

the power industry full package of power generating units in the form of 600 MW super-critical and super-super-critical, 1,000 MW super-super-critical, 1,000 and 1,200 MW secondary reheat, E, F and H class CCGT, second and third generation nuclear, 1.25 MW to 6 MW wind and concentrated solar power.

SEG delivered dozens of GT of 10 MW or below in the initial years between 1958 and 1983 and the largest one was 25 MW class. They were however insufficient in meeting the expanding economy and the demand of electricity in China, and external support was needed for the necessary technology breakthrough. Therefore, in 2003, SEG introduced Siemens technologies of E and F class GT as well as its associated combined cycle blocks. After the technology transfer, SEG was able to manufacture E and F class GT based on Siemens design and follow Siemens procurement specification for auxiliaries.

However, the technology transfer from Siemens had certain shortfalls and limitations for SEG. Firstly, although SEG was transferred the GT manufacturing technologies, the GT design know-how was withheld from it. Secondly, the technology transfer did not include the GT hot parts and GT reparation capabilities, which were still held by Siemens. Thirdly, the core aftersales services were under Siemens control and hence in association, fourthly, SEG GT products could only sale within the Chinese domestic markets. In spite of SEG successfully supplied GTs to Belarus, Bangladesh and Argentine, SEG had to partner Siemens in becoming its sub-contractor in these overseas sales.

Gas Turbine Journey with Ansaldo Energia

From 2012, the GT industry has undergone a series of restructure:-

- In 2012, a joint venture between Mitsubishi Heavy Industries Ltd. (MHI) and Hitachi Ltd. was established
- In May 2013, MHI acquired Pratt & Whitney Power System
- In May 2014, Siemens acquired Rolls-Royce Energy GT and Compressor business
- In November 2015, General Electric (GE) acquired ALSTOM power and grid business
- In February 2016, Ansaldo Energia (AE) acquired ALSTOM GT26 and GT36 technologies from GE

In May 2014, on the other hand, SEG acquired 40 % of AE shares, becoming the second largest and the sole technology shareholder of AE after Cassa depositi e prestite S.p.A., which is a financial investment firm. In November of the same year, SEG and AE formed two (2) GT joint ventures, synergising the R&D, manufacturing and sales and aftersales capabilities of both companies in the GT business. The manufacturing bases in Shanghai, China and Genoa, Italy jointly achieves production capability of 40 GTs of the same technology platform per annum. SEG focuses in the markets in Asia, Australasia and 50 Hz Latin America, while AE primary serves the Mediterranean and American markets. SEG also champions projects financed or sponsored by the Chinese institutions.

The result of maximised indigenisation is the SEG may fall the prices of equipment packages and services to 30 % and 40 % of the imported equivalences respectively, reducing the cost of power production from CNY 0.03 per unit using imported power blocks to CNY 0.01 per unit.

Gas Turbine

SEG AE series GT compressors emphasis high flow rate, high pressure ratio and high efficiency. Their blades are surface coated by anti-corrosion layer to adapt the costal operating environment.

The SEG eight (8) stage turbine blades are made of advanced single crystallite cobalt- and nickel-based high temperature material. Imported from Italy, the cast turbine blade surfaces are treated by SEG in-house air plasma spray to form a thermal barrier coating (TBC) for combating against hot corrosion. The inner metal transitional layer is formed by firing the metal powder, melted in the combustion of nitrogen at 3,000 °C, on the cast turbine blade surface in Mach 3 to 4 in a plasma arc of 30,000 °C. The outer ceramic layer is attached to the inner layer by the same plasma arc method. The ABB made robotic arm programmed to follow the blade profile and maintain the spray is always perpendicular to the surface, while the coated turbine blades are laser punched to create the film cooling holes. The resulted turbine blades, shielded by TBC and cooling air film, can withstand the combustion temperature at as high as 1,400 °C and maintain their body temperature at maximum 800 °C.

Although China is capable to cast turbine blades for operating in maximum 800 °C since 1960s, the 30 % passing rate of the cast turbine blades for surviving in over 800 °C working medium is too low to be economical to cast indigenously. As a result, same as other GT original equipment manufacturers, SEG sources the casted turbine blades from Italy and performs surface treatment in-house. Each Italy made cast turbine blade is said to be worth a B.M.W. 7 series saloon, while each GT comprises 80 turbine blades. Simultaneously, SEG is pursuing indigenisation of casting GT turbine blades.

SEG also possesses the capability of repairing damaged turbine blades by laser direct metal deposition. Adopting three-dimensional printing technique, the molten metal powder is brazed on the blade tips at 2,000 °C, while the repaired turbine blades are able to survive 33,000 equivalent operating hours (EOH). The SEG turbine blades process workshop floor is said to be susceptible to the Huangpu River tidal movements, while the U.S. made turbine blade reparation equipment is highly sensitive to ground displacements. The solution is a massive 1 m thick concrete slab with 0.5 m long piles was constructed, which costed CNY 30 million, to counter the tidal thrust with its own weight in order that that the turbine blade reparation equipment installed on it may enjoy the highest degree of ground stability.

The low nitrogen oxide (NO_x) burners support on-line fuel switch between gas and light oil at 50 % load and under 50 mg/Nm³ NO_x emission. The fourth generation burners for F class GT has achieved 99 % combustion efficiency and 15 ppm NO_x emission, contributing the improvement of the combined cycle efficiency by over 0.2 % or over 14 MW additional output. Also, their achieved noise level of 75 dB has satisfied the Chinese national standard requirement of 85 dB with ample margin. Besides, the SEG burners are said to be capable to combust up to 10 % of hydrogen in the gaseous fuel.

SEG AE94.2K(S) series GT, endowed with reduced compressor total area at the air intake, features the capability of combusting low heating value and high carbon dioxide fuel gas of as low as 3 MJ/Nm³ from coal-to-gas process, furnaces and cock ovens.

SEG GT is built with 100,000 EOH by design. Should a GT be in a peak lopping operating regime, 60,000 EOH are at its disposal.

Steam Turbine

As a total combined cycle solution provider, SEG also designs, manufactures and supplies steam turbines (ST). Since 1953, SEG, with the annual ST production capacity of 36,000 MW, has delivered over 1,000 units of ST from 6 MW to 1,200 MW, which accumulated total installed capacity of 350 GW is equivalent to 40 % of total installed thermal power capacity in China. For combined cycle applications, SEG started supplying ST on one-by-one configuration with an E class GT in 2000 and in 2017, SEG has coupled ST with a H class GT on one-by-one configuration.

SEG ST features modular design in the following order:-

- High Pressure (HP) single-casting module
- Intermediate Pressure (IP) single-casting module
- IP dual-casting module
- Low Pressure (LP) dual-casting module
- HP/IP Combined module
- HP/IP/LP Combined module
- IP/LP Combined module

The SEG HP and IP modules are standard in the steam parameters and the unit capacity, permitting different HP and IP module outputs are attained by varying only steam flow rate. The SEG LP modules are sized according to steam volumetric flow rate and their steam flow path is universal. All SEG HP, IP and LP modules share in common sliding key system, cylinders, rotors, bearings, valves and piping design, as well as the axial vibration characteristics and balance of plant systems.

The SEG LP end blade height is determined by the steam volumetric flow rate and the LP end blade inlet-outlet area ratio of 1.26 for the adaption of higher back pressure. Currently, SEG has achieved the following blade heights in their respective LP rotational speed:-

LP Speed [r.p.m.]	LP End Blade Height [mm]	
	Achieved	Under Development
1,500	1,710	1,905
3,000	1,220	1,430

The SEG ST exhaust can be either axial or downward, suitable for turbine hall of small footprint and limited height respectively. SEG would, however, prefer the single shaft units to adopt axial exhaust, and multi-shaft downward.

SEG ST can couple with GT or a generator in a single shaft arrangement with or without a synchro-self-shifting clutch. The ST casings and rotor are fully integrated and tested in the SEG workshop before shipment to site, saving site installation time and warranting equipment precision. The ST lubricating oil system is also supplied to site in a complete module, offering easy site installation, testing and commissioning.

The overhaul of the 100,000 EOH embedded SEG ST is scheduled in the following order:-

Overhaul	Planned Works in 30 Years Asset Life
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	5 Year Cycle	10 Year Cycle
Minor	12 times	6 times
Intermediate	6 times	3 times
Major	5 times	2 times

Generator

Generators are manufactured by Shanghai Electric Power Generation Group (SEPG) under SEG. Since the establishment in 1953, it has delivered accumulated 300 GW of power generation capacity with its current 30 GW annual production capacity. It has also accomplished the world's first 660 MW dual water-cooled generator in May 2017, first 1,200 MW water-hydrogen-cooled generator in June 2017 and first 300 MVA_r water-water cooled synchronous condenser island in September 2017.

SEG four (4) series of water-hydrogen-cooled (bi-polar and quadro-polar), all hydrogen-cooled, dual water-cooled and air-cooled generators feature high level of modular design and three dimension production visualisation, offering the following matches for the CCGT applications and performance advantages:-

GT Class	Generator Type		
	Single Shaft	Multi-Shaft	
		One-on-one	Two-on-one
H	800 MW H-W	500 MW W-H + 250 MW H-H	2 x 500 MW W-H + 500 MW W-H
F	500 MW W-H	300 MW W-H ^{Note 1}	2 x 300 MW W-H + 300 MW W-H ^{Note 2}
E	Nil	180 MW A + 100 MW A	2 x 180 MW A + 180 MW A
6F	Nil	80 MW A + 40 MW A	2 x 80 MW A + 80 MW A

H-W: water-hydrogen cooled generator

H-H: all hydrogen-cooled generator

A: air-cooled generator

Note 1: top lead model

Note 2: bottom lead model

Generator Type	Characteristics	Advantage	Result(s)
H-W	Coil axial ventilation	Overall length may reduce 10 %	
	Multi-stage extraction	5 to 8 K temperature rise lower and 5 % volume flow higher than single stage extraction	<ul style="list-style-type: none"> 99.03 % maximum efficiency 99 % efficiency at 300 to 500 MW output
H-H / A	Sectional stator coil cooling	Low temperature uneven coefficient	
	Variable flow path for stator coil cooling	Effective suppression of coil temperature rise	<ul style="list-style-type: none"> Improved output capacity

Generator Type	Characteristics	Advantage	Result(s)
	Dual path for rotor tip cooling	Effective suppression of rotor hot spot temperature	

The generator rotor and stator are fully integrated for most models for easy transport to site, while installation is well assisted by the pre-installed guide rails at site.

HRSG

Part of SEG and the successor of Anderson Meyers & Co., Ltd. established in 1906, Shanghai Boiler Works Co., Ltd. has designed, manufactured and delivered 12, 24 and one (1) sets of horizontal type HRSG for 6F, 9F and H class CCGT respectively, in triple pressure reheat and double pressure with supplementary firing models. ALSTOM HRSG technologies were introduced in 2003.

Contrary to the conventional approach of attaching the finned tubes directly to the manifold which results in high thermal stress and complicating production methods, SEG HRSG adopts the stepped arrangement of manifold-header-finned tubes. A manifold is branched into multiple headers of smaller diameter and thickness and the finned tubes are attached to the headers. The saving from the use of bents on the finned tubes and the reduction of the weld joint quantities contribute the reduction of the thermal stress from the conventional approach by 60 %, enhancing operational safety and reliability.

SEG HRSG follows C-Frame for construction. The HRSG frame is first constructed at site, while the modularised pressure parts are then lifted and inserted in location within the frame, forming part of the HRSG casing. Such HRSG construction method minimises the site weld joint quantity and hence enhances the installation quality and shortens the construction period.

SEG 6F- and H-class HRSG characterises the following HP, Re-Heater (RH), IP and LP parameters:-

Class	HP	RH	IP	LP
6F	109 t/h 558 °C 7.2 MPa	Nil	Nil	18.8 t/h 264 °C 0.66 MPa
H	453.6 t/h 602 °C 17.2 MPa	494.8 t/h 585 °C 3.5 MPa	63.6 t/h 356 °C 3.7 MPa	42.9 t/h 280 °C 0.6 MPa

SEG H-class HRSG features once through HP. The elimination of the high thickness HP steam drum significantly alleviates the thermal stresses in the system and hence improves the agility of the HRSG response to demand variations. Also, the heat exchange surface area of H-class HRSG is 45 % larger than of F-class HRSG.

Planned Maintenance

SEG sets the following tasks to be performed in CCGT planned maintenance:-

Regime	Tasks
Minor	<ul style="list-style-type: none"> • Combustors inspection • ST first and fourth stage blade inspection • Compressor first stage blade inspection • Exhaust diffuser inspection • Air inlet system inspection • Damaged thermal insulation ceramics replacement
Intermediate	<ul style="list-style-type: none"> • All tasks in Minor Regime • Partial open of ST casing • ST rotor and stator blade replacement • ST inspection
Major	<ul style="list-style-type: none"> • All tasks in Intermediate Regime • GT casing open • Rotor removal • Compressor inspection • Compressor blade dismantlement and cleaning

Remarks

SEG is the forefront total CCGT solution provider in China, designing and developing, manufacturing, supplying and supporting GT, ST, generator, HRSG and the auxiliaries under a single roof. Its GT technologies, built on the foundation of Siemens, AE and ALSTOM, are advancing with much focus and effort on indigenisation. Its emphasis of high degree of modularisation should offer the CCGT solutions high flexibility in satisfying the customer needs. There is no doubt that SEG will continue leading the Chinese power industry to meet the ever-increasing power demand in the mainland with its advanced, clean and efficient CCGT products and services. The offer of the delegates of IMechE-HKB, HKIE-G&E and IGEM-FEDS to visit the state-of-the-art TBC application and reparation of the GT blades was a demonstration of SEG confidence in its technologies, as well as SEG generous support to the gas and energy industry in Hong Kong, for which IMechE-HKB, HKIE-G&E and IGEM-FEDS are particularly grateful.

IMechE-HKB, HKIE-G&E and IGEM-FEDS thank Mr. Jian-Hua Yuan, SEPG Vice President and GT Business Department General Manager, and his colleagues for their reception and hospitality.

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