Efficiency Improvement Possibilities in CCGT Power Plant Technology

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1. Introduction.

Current status in the large Combined Cycle Gas Turbine (CCGT) technology is missing the instant before the first contractually guaranteed 60%-efficiency CCGT power plant comes on stream.

The biggest chances to reach this long-expected benchmark are ascribed to large heavy-duty Gas Turbine (GT) models coming from four top manufacturers at once.

These are 7001 & 9001 F & H series from General Electric (GE), ATS 501 model from Siemens Westinghouse, GT series 94.3A from Siemens Power Generation, GT24/26 from Alstom and at the last but not least the 501 / 701 F & G models from Mitsubishi Heavy Industries (MHI).

The following examples of GT technological elements are considered as promising determinants for further intensive growth in CCGT power plant thermal efficiency:

- Turbine Inlet Temperature (TIT) reaching level of 1400°C and above.
- Exhaust gas temperatures in the region well above 600°C.
- Sustained improvement in special cooling techniques, especially integrated closed-loop steam cooling technique.
- Further progress in metallurgy status, especially directionally solidified single crystal blades.
- The use of ceramics.
- Utilization of improved thermal barrier coatings with great durability.
- Optimized compressor and turbine aerodynamics.
- Advanced control system technology.

All the mentioned large industrial GTs with unit output in the range of 180 MW and above with exhaust gas temperatures well above 600°C can benefit from higher pressure and temperature supercritical heat recovery steam generator (HRSG) technology.

So we can say that commercial implementation of supercritical technology in the water-steam cycle within the frame of CCGT power plant is not any more a vision. Once-through single-pass Benson boiler using high nickel alloys for high pressure and temperature components might be employed.

Maximal utilization of process waste heat, optimization of entire CCGT cycle in respect of cooling systems, fuel supply systems and other balance of plant equipment shall also pay great contribution to highest efficiency figures.

However, 60% CCGT efficiency is only an intermediate step on the way to higher targets. The US Department of Energy’s Vision 21 program is aiming for a goal of over 70 – 75% thermal efficiency for CCGT power plants in 21st century.

2. General.

Deregulation, liberalization and privatization of the energy sector have accelerated technical progress in CCGT technology.

In the last decades, one of the most important objectives in the development of CCGT technology was to minimize the life-cycle costs.

In other words, to reduce the total expenses arising from the power plant operation during its entire service life.

This was mainly driven by massive expansion of Independent Power Producers (IPPs), which have been, and of course they always are very much interested in most competitive power generation price (i.e. kWh-price) at minimum expenses and highest equipment availability.

IPPs recognized that the gas fuelled low-cost, low-emissions, most efficient CCGTs are becoming workhorses for new power generating plants in the power generation industry.

Five major factors are driving the development of new CCGTs:

- First, they are very efficient in operation.
- Second, the specific installation costs of new CCGTs are low.
- Third, the time needed to install GTs is also low, averaging under a year for simple-cycle operation and around two years for CCGT operation.
- Fourth, they are most environmentally friendly of all the fossil-fired power plants.
- Fifth, the space requirement is significantly lower than other related technologies.

The main power generation cost factor is the fuel price and fuel consumption. Since IPPs are not able to influence the price of the fuel, their main objective is to minimize the fuel consumption, in other words to maximize the overall power generation efficiency without affecting the equipment safety, availability and lifetime.

However, beside thermal efficiency and availability there are also other important aspects that can be improved.

For example the time between when the CCGT power plant is ordered and when it starts producing electricity, but this is not subject of this document.

The demand for lower electricity prices and the competitive pressures under which the IPPs have to operate is forcing them to pass part of the burden on to the power plant manufacturers.

The most critical performance characteristic of any fuel burning power plant is, however the thermal efficiency.

The combination of most GTs, which achieve highest efficiency, with supercritical technology in the water-steam cycle within the frame of CCGT power plant is the main driving factor in the future development of CCGT technology.

Figure 1 shows how overall efficiency of open cycle gas turbine (OCGT) and CCGT power plants have improved since 1950.

The efficiency of OCGT power plants has doubled, and with the advent of CCGT power plants, efficiency has tripled in the past fifty years.

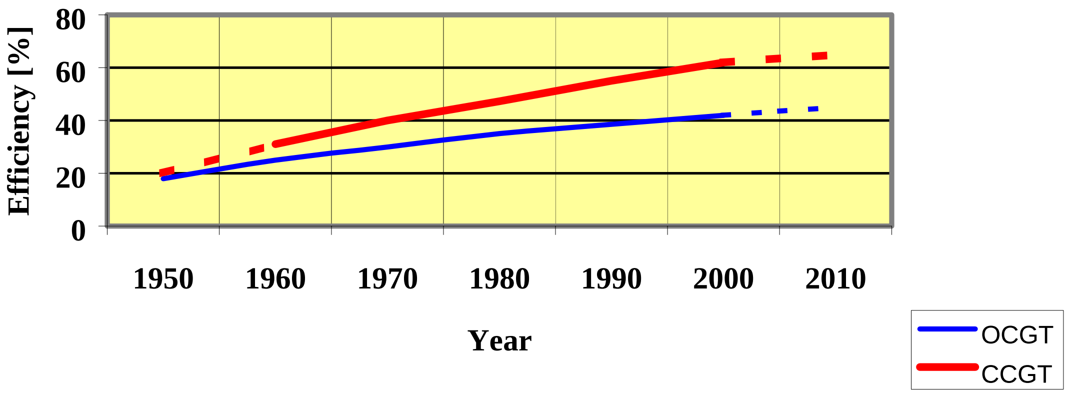


Figure 1
Development of GT and CCGT Efficiency

The present state-of-the-art in CCGT efficiencies and specific investment costs of latest CCGT power plants have achieved parameters unrivalled by any other power generation technology, however we can say that the thermal efficiency is most probably CCGT's single strongest selling point.

3. Latest Generation of Large Heavy Duty GTs.

Extensive research and development in the GT technology sector has led to CCGT efficiencies up to 58% in the past and is approaching 60% benchmark at the present. GT technology development of recent years has contributed towards this remarkable progress more than the development of steam turbine based bottoming water-steam cycle, which, on the other hand, achieved its mature status earlier.

List of selected most advanced models of large heavy frame & heavy duty GTs that is compiled in Table 1 reflects the present level of technical progress in this category.

Table 1
Performance Specifications of Large Advanced Heavy Frame GTs
(ISO Conditions & Natural Gas Fuel-LHV & Generator Terminals)

Manufacturer	GT Type	Power Output MW	Efficiency %	Pressure Ratio	Exhaust Mass Flow kg/s	Est. TIT °C	Exhaust Temp. °C	Frequency Hz
Alstom Power	GT24	179	39.5	30	391	1300	640	60
	GT26	262	40.3	30	562	1300	640	50
GE Power Systems	7001G	240	39.5	23	558	1430	572	60
	9001G	282	39.5	23	685	1430	583	50
Siemens Westinghouse Power Corp.	501F	185	37.0	15	456	1350	596	60
	501G	254	39.0	19	553.4	1427	590	60
	94.3A	260	38	17	640	1190	562	50
Mitsubishi	501F	181	38.6	16	453	1350	607	60

Heavy Industries	701F	265	39.9	17	651	1350	596	50
	501G	250	40.4	20	567	1500	586	60
	701G	328	41.3	21	737	1500	587	50

Last year, GE Power Systems announced the first two installations for its next generation of GT technology, the GT Model MS7001 H (60 Hz) and MS 9001H (50Hz).

The 60Hz units will be installed in 800 MW Heritage Power Station, NY, USA. The power station shall go into commercial operation in 2003.

The 50Hz unit is being installed in 500 MW CCGT power plant at Baglan Energy Park, SW, United Kingdom and shall go into commercial operation in 2002.

As already stated both power plants highlight the latest advancements in turbine design, breaking through the 60% CCGT efficiency barrier, long considered the "four minute mile" the power generation industry.

Both GT models are aero derivatives and their compressors are 18-stage scale-up versions of the CF6-80C2 aircraft engine.

Siemens-Westinghouse is very close to having a GT that may break the 60% barrier as well, designated as 501 ATS. The GT cooling system employs closed-loop steam cooling for efficiency augmentation.

Variable vanes were added to the first two compressor stages. Active blade-tips clearance control on the first two compressor stages with improved rotor sealing are contributing to improvement in power output and efficiency.

Advanced compressor will have pressure ratio 29:1 and the blades will be of single crystals. GT blades have thermal barrier coatings and the first two row vanes will be steam cooled. The first 501 ATS is expected to be completed this year.

One of the most powerful GTs, which is already in commercial operation, is the 60Hz GT Type 501G. This GT, which was developed in co-operation with Siemens-Westinghouse, Mitsubishi and Fiat Avio, is the largest and one of the most efficient 60Hz machines built to date, delivering in open cycle an ISO power output of 230 MW.

Most important design elements of 501G are combustors with steam cooled transition ducts. This makes possible to spare cooling air, which is thus available for lean, premixed combustion. GT has directionally solidified blades and vanes in first and second row.

MHI have developed a 50-Hz derivative of model M501G, designated as M701G, which is rated at 334 MW at the 1500°C design GT inlet temperature. This represents the biggest model in commercial operation by now. ISO thermal CCGT efficiency above 60% can be achieved with both GT models.

The first and second GT stage blades have a thermal barrier coating as well as being air-cooled. The third and fourth stage GT blades are shrouded as they are on the earlier 701F design. The GT blades and vanes are made from new nickel alloys developed by MHI in conjunction with Mitsubishi Steel Manufacturing Company.

The MGA2400 alloy used for the vanes has improved welding characteristics. The MGA140 alloy used for the blades has good creep strength. The first two stages of blades use directionally solidified alloy to further improve creep strength.

The first four M501G units are in commercial operation in 1610 MW CCGT Higashi Niigata power plant, Japan since 1999.

Siemens KWU has successfully introduced its largest, 260 MW GT model V94.3A (50Hz) in commercial operation.

It is interesting to note that first four GT models V94.3A are scheduled for commercial operation in CCGT power plants in the host country of this conference, in Malaysia, in 2003.

The most important design elements of this GT are the first GT stage blades, which are directionally solidified single crystals and the annular combustion chamber with uncooled, all-ceramic combustion chamber tiles and dry low NOx hybrid burner.

Use of uncooled ceramic tiles makes more combustion air available for the hybrid burners, which produce less thermal NOx as a result. This is on the other side a great potential for increasing the TIT.

For better illustration, longitudinal section of the V94.3A GT is shown in figure 2.

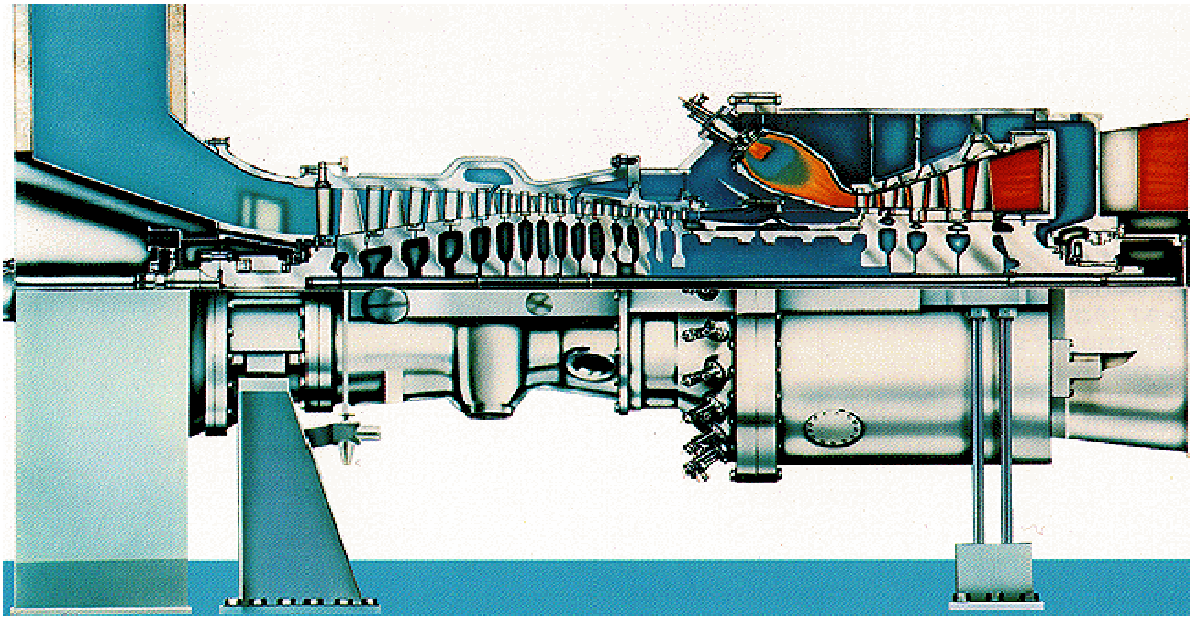


Figure 2

Longitudinal Section of the V94.3A GT

Unique GT design was introduced by Alstom (former ABB) with GT Type 24 (60 Hz) and GT Type 26 (50 Hz).

Both GT Types have been equipped with sequential combustion system consisting of two combustion chambers, which are arranged downstream two independent fuel injection systems. This design offers most competitive efficiencies as well as very good part-load flexibility as well. Both models can achieve 58% efficiency in CCGT operation.

One of the first power plants equipped with GT 26 the 780 MW CCGT Rocksavage power plant in United Kingdom is in commercial operation since 1999. High exhaust gas temperature of 640°C makes this GT predestined for multiple-supercritical pressure reheat steam cycle in the bottom steam-water cycle.

4. Boosting CCGT Efficiency.

The never-ending race for best fuel utilization is accompanied by parallel effort to reduce investment and operational costs, improve the equipment availability and at last but not least to minimize emissions.

Power generation equipment manufacturers, especially GT designers are creating the next generation of machines by adapting existing designs as mach as possible.

Scaling proven parts up or down enables engineers to draw on proven aerodynamics, performance characteristics, and materials when designing parts for new turbines.

A much more expensive alternative is designing from scratch.

All present GT manufacturers share certain design features that illustrate trends in GT manufacturing: dry-low-emissions combustors, variable compressor vanes, dual-fuel systems, single-crystal cast blades, and advanced cooling systems.

Dry-low-emission combustors replace water or steam injection systems used for emissions controls in the past, which can add to the GT and operation overall cost, particularly in desert regions.

Variable compressor vanes enable operators to optimize the turbines for different ambient conditions and at CCGT part load operating regime.

Dual fuel systems enabling to burn natural gas or distilled oil ensures GT and/or CCGT operation if either fuel becomes too expensive or less available.

Improvements that allow an increase in CCGT efficiency have been identified by as:

- ⇨ Increasing TIT and GT exhaust gas temperature.
- ⇨ Optimizing of compressor and turbine aerodynamics.
- ⇨ Minimizing irreversibility within the HRSG.
- ⇨ Keeping overall CCGT heat losses as low as possible.
- ⇨ Employing advanced control system technology.

In the following we address the technological responses to each of these.

4.1 Turbine Inlet & Exhaust Temperature.

The best way to increase cycle efficiency and specific power output (kW/masflow) is to increase the compressor pressure ratio and the TIT.

GT designers have always struggled to raise TIT without damaging or reducing a design life of GT components. Because the GT power cycle is limited by the Carnot cycle, the higher the temperature and pressure at which heat is added the higher the efficiency.

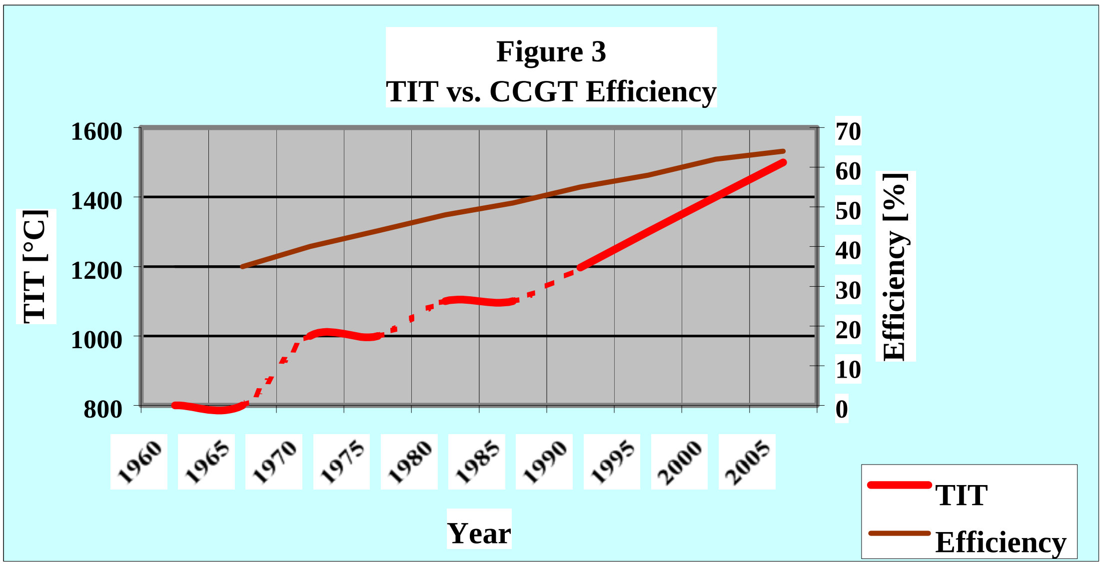
The limiting factor in this approach is the ability of the GT blades and vanes, rotor and stator materials as well as combustor materials to withstand high temperatures during the entire design life time period.

There are several technological solutions to this limitation: advanced cooling of the GT hot gas path components, using advanced temperature-resistant materials and heat protective coatings.

Around 50 years ago, the first generation of GT have not employed any cooling systems, so they have been working with very low TIT in the range of 700°C - 800°C. Later, in the seventies the GT designers developed simple conventional cooling methods for GT blades and vanes, which allowed them to increase in stages the TIT up to 1000°C - 1100°C in the middle eighties.

This was also limited to conventional cooling method and in order to go to higher temperature regions, advanced film cooling methods as well as new materials, better than used Ni-based alloys had to be introduced.

Figure 3 shows correspondence between TIT and CCGT efficiency during the CCGT development period between 1960 and 2005.



With regard to cycle efficiency the optimal TIT lies in the region of 1400°C - 1600°C at compressor pressure ratio between 20 and 40 for compressors without intercooling and 40 – 60 for intercooled compressors, at specific GT power output of 400-500 kW/kg/s.

Technological improvements in GT cooling technologies have come largely from aircraft technology.

Cooling technology has progressed in a series of discrete steps as advanced production techniques and finite element analysis computer codes allowed ever more intricate and tortuous cooling paths to be built into GT rotors, stators, blades, vanes and combustion systems.

GT using closed circuit steam cooling can easily maintain TIT in the range 1500°C to 1600°C.

For example, by eliminating combustor cooling air from a steam cooled combustion chamber wall, all the combustion air can be introduced into the primary combustion zone in order to maintain the flame temperature at acceptable level i.e. not higher than the flame temperature of “lower” rated unit without steam cooling.

Not only the development of cooling technology, but also material advancement have benefited from improved manufacturing and metal forming techniques.

Material properties have also improved through advanced material production methods such as directionally solidified metals and crystallization to the extent that "single crystal" turbine blades can be made.

Because materials usually break across the interface of two crystals, single crystal casting makes parts inherently stronger and corrosion-resistant.

Use of ceramic materials shall also contribute to GT performance economics. Such materials are already successfully in use in GT combustion systems (e.g. Siemens) at the present time.

Si_3N_4, a candidate ceramic material for the high-temperature components, is much more brittle than metals, while its thermal expansion coefficient is almost one-fourth that of typical heat-resistant alloys.

Considering these characteristics, there are many possibilities for utilization of this material for new generation of heavy duty GTs.

The “ceramic” GT using the key technologies, such as monolithic ceramics may be the CCGT prime movers leading this technology to OCGT efficiencies in the range of 45% and above.

As long as the large “ceramic” GT is only future vision, and the designers cannot go much further with metallurgy, a combination of advanced cooling of the GT hot gas path components (such as blades, vanes, combustors, rotor and stator heat shields) extend their performance life.

The use of GT blades, vanes and other high temperature exposed components with a high insulation thermal barrier coating (HITBC) makes it possible to raise the TIT still further without detriment to the design life.

Improvements to the film cooling and the procedure for application of the TBC coating make it possible to significantly extend the design life of the coatings.

The future objective of HITBC designers is to develop a new generation of thermal barrier coating systems with enhanced thermal insulation capability for the protection of hot section components in power generation technology: aero and land-based GT blading, combustors and other high temperature components.

The developments from HITBC will bring far-reaching benefits to GT performance economics, component lives, reduced exhaust emissions etc.

Once more it shall be emphasized that the application most advanced full-coverage-film-cooling of GT blades and vanes, introduction of open and closed steam cooling systems, use of thermal barrier coatings and directionally solidified blade technologies and at last but not least wide application of ceramic materials can pay a great contribution to unmatched performances of future advanced GTs for power generation.

Because the characteristic of GTs is the incentive to operate at as high TIT as the prevailing technology allow. This incentive comes from the direct benefit to both, specific power output and thermal efficiency.

Associated with the high maximum TIT is a high exhaust gas temperature, which is not utilized in OCGT, represents waste heat dissipated to the atmosphere.

On the other hand it is of precious, high value heat energy for the bottoming water-steam cycle of the CCGT.

Exhaust temperatures of the most advanced GT models achieve 600°C and above. This makes possible that the steam bottoming cycle goes supercritical.

Supercritical condition can be applied to Heat Recovery Steam Generator (HRSG), which have Once-through Steam Generation (OTSG) design.

Neither OTSG nor supercritical conditions are new. But both are new for CCGT system. Traditional use of natural circulation via a steam drum is not possible under such condition.

Therefore the OTSG / HRSG becomes necessary. Supercritical temperatures and pressures are given by material selection at present.

This not only affects the boiler but also the turbine steam jackets. Some austenitic components with 12% Mn and 25% Ni will be required for the next generation ultra supercritical boilers.

Operation flexibility is another benefit for OTSG boiler arrangement. It is configured as serpentine tube bundle with no need for circulation pumps. Phase change takes place along the tube serpentine.

There is no HP drum and there are no thick walled tubes. A smaller volume of water is heated. The thermal inertia of the system is lower and the boiler heats up more rapidly from a warm start.

For example G-class GT in association with triple pressure reheat supercritical cycle (with HP steam pressures up to 280 bar and HP steam temperatures around 570°C can achieve thermal CCGT efficiency close to 60%.

In other words, most of the large GTs that are available on the market, such as V94.3A, 501/701G, GT24/26 and of course also GE F & H-Class GTs can benefit from higher pressure supercritical HRSG operation.

Performance specifications of advanced CCGT units are shown in the Table 2.

Table 2
Performance Specifications of Advanced CCGT Units
(ISO Conditions-Base Load & Natural Gas Fuel-LHV & Generator Terminals)

Manufacturer	CCGT Model Designation	Total CCGT Output MW	Thermal Efficiency %	GT Number & Model	Power Output GT MW	Power Output ST MW	Frequency Hz
Alstom Power	KA 24-1	260	56.6	1 - GT24	176	84	60
	KA26-1	378	57.0	1 - GT26	258	120	50
GE Power Systems	S107FB	280	57.3	1-MS7001FB	181	99	60
	S109FA	391	56.7	1-MS9001FA	252	139	50
	S 107H	400	60.0	1-MS7001H	**MONO-BLOCK**		60
	S 109H	480	60.0	1-MS9001H	**MONO-BLOCK**		50
Siemens Westinghouse Power Corp.	2.W501F	561	55.8	2 - W501F	2x182	197	60
	1S.W501G	365	58.0	1 - W501G	250	115	60
	GUD2.94.3A	705.0	57.3	2 - V94.3A	2x256	282	50
Mitsubishi Heavy Industries	M501F	281	56.7	1 - M501F	178	103	60
	M501G	371	58.0	1 - M501G	247	124	60
	M701F	398	56.9	1 - M701F	262	136	50
	M701G	484	58.2	1 – M701G	324	160	50

4.2 Irreversibility within the HRSG.

A dominant feature in CCGT power plant development is minimizing the irreversibility of the HRSG.

Irreversibility can be reduced by raising steam in the HRSG at pressures closer to the optimum.

An increase of above 5 percent CCGT efficiency comes from changing from single to double pressure steam rising.

Although the gain of going from double to triple pressure steam raising is only about 1-2 percent and involves additional power plant complexity and cost, most of the new modern CCGT power plants incorporate triple pressure raising.

Block schematic for a typical triple pressure HRSG with reheat steam cycle is shown in the Figure 4.

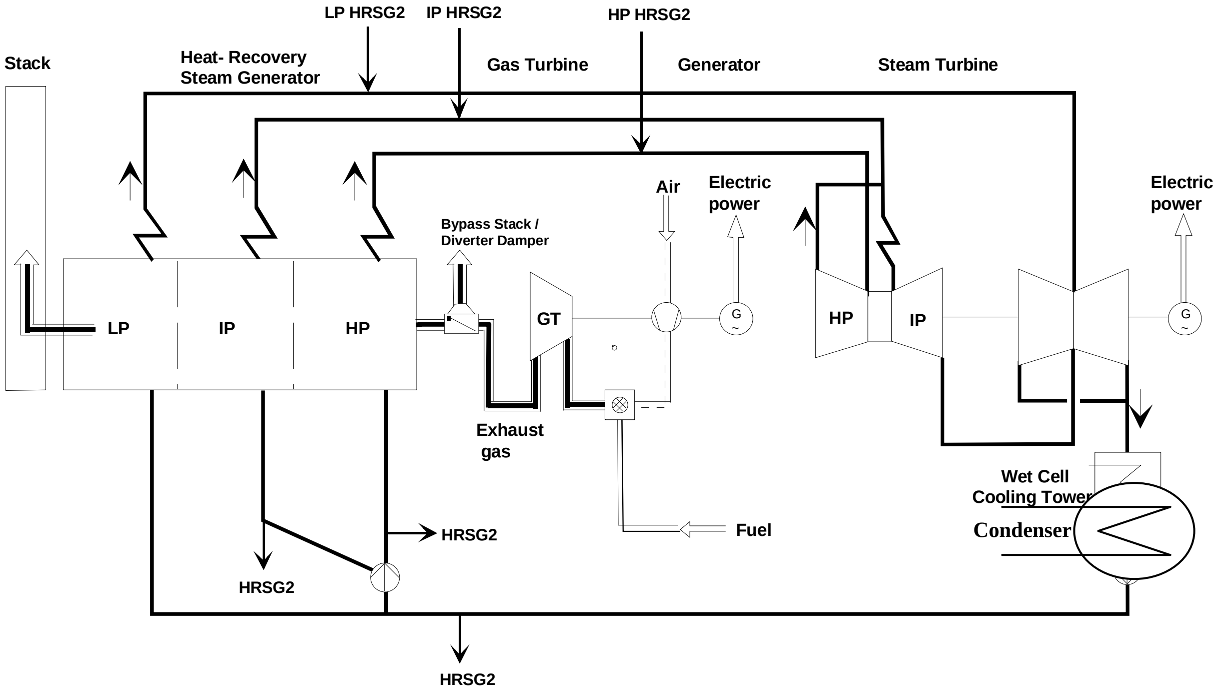


Figure 4

Typical Triple Pressure HRSG with Reheat Steam Cycle

Most important step towards minimizing irreversibility within the HRSG is the employment of supercritical-high pressure steam cycle as described above.

Combination of this system with latest generation of future large GTs can push the magic, and most probably the top, efficiency towards 70% to 75% targeted by US Department of Energy’s Vision 21 program which is aiming for a goal this challenging figure for CCGT power plants in the 21st-century.

4.3 Minimizing overall CCGT Heat Losses.

In maximizing the efficiency of a CCGT power plant the designer has to optimize the balance between the HRSG efficiency and the steam cycle thermal efficiency.

The main goal is to minimize overall heat loss and to maximize the CCGT efficiency. For example, minimizing its flue gas temperature can drastically increase the efficiency of HRSG.

On the other side, depending on GT fuel quality, this may reduce steam cycle efficiency or necessitate steam cycle feed heating.

The balance has been struck by designing for a relatively high HRSG efficiency and accepting a somewhat lower steam thermal efficiency, for a net gain of CCGT efficiency.

This is mainly practical in natural gas fired CCGT power plants because the low sulphur content of natural gas allows low stack temperatures to be employed while still avoiding corrosion of the water tubes.

Figure 5 shows triple pressure, reheat HRSG simplified flow diagram.

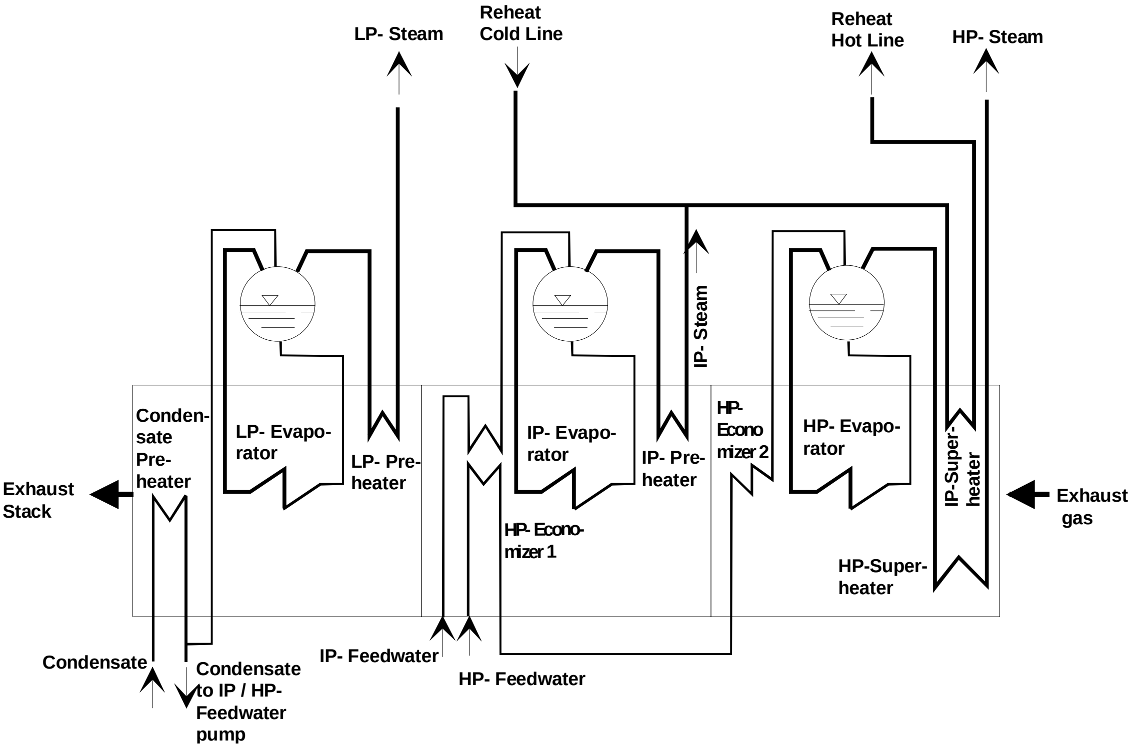


Figure 5

Triple Pressure, Reheat HRSG Simplified Flow Diagram

Fuel preheaters using low-grade waste heat from HRSG cycle also contributes to heat loss reduction, however the efficiency increase will not exceed 0.5 – 0.8 %, which is rather low compared to system complexity and additional costs.

4.4 Advanced Control System Technology.

Improving sensors and control systems could be another way to boost future OCGT and CCGT efficiencies. For example, today's GTs control TIT indirectly – by measuring the exhaust gas temperature and the heating value of the fuel, then mathematically calculating the peak combustor temperatures.

But temperatures in a turbine’s hot gas path can vary by as much as ± 25ºC, making it difficult to control firing temperatures precise enough to achieve top efficiencies.

Similarly, there is no current way to assess wear of turbine components within the hot gas path in real time, without shutting down the turbine.

Consequently, maintenance and component replacements are often scheduled on conservative design practices based on historical data.

Both problems can be resolved by developing a suite of novel sensors that would measure combustor flame temperature and hot-gas-path component life directly. The sensors and controls would be applicable to both new and existing turbines.

In this respect, all novel concepts in OCGT and CCGT control technology shall incorporate condition monitoring and fault tolerance.

The system reliability must be defined in terms that include the process controlled (i.e., the OCGT and CCGT) and not simply the controlling components.

Fault tolerant considerations for both the instrumentation points and the control system can be addressed by means of an expert system coupled with a modelling system.

In the subject control system, an online, background running hybrid expert system shall compare real time input data from instruments to calculated thermodynamic and mechanical parameters.

These calculations are then used to determine data deviations and component performance degradation. Further, a diagnostic system is able to make fault tolerant decisions based on prioritized rules.

This is of special concern since the scientific functions of the system could potentially overwhelm an operator. Separate operator and engineer workstations would be necessary to maximize the usefulness of the system.

5. Summary - Conclusions.

- Especially during the past decade, the technological innovation in CCGT power generation systems has been strongly influenced by new market conditions and vital changes as a result of spreading liberalization and deregulation accompanied by competitive forces as well as with manufacturers R&D spending. The result of this technological innovation encompasses the development path from all potential designers earliest CCGT power plants (BBC, ABB, GE, KWU-Siemens, WEC, MHI and others) through the “B”, “C”, “D”, “E”, “F”, “G” and “H” technology, leading CCGT power plant technology into the twenty-first century.

- It is expected that the CCGT efficiency parameters in the class of large heavy duty GTs with 180 MW and above may achieve the level between 62% and 65% by the year 2015. Even at that such a goal looks realistic; it is very much depending on further development of high temperature metallic materials as well as ceramics with acceptable temperature resistance and stress characteristics.
- A very good chance to reach such challenge has the combination of advanced GT technology with supercritical, reheat steam bottoming cycle. However, this is again very much depending on the future design and also price development in the HRSG industry.
- With the advent of new technologies like inter-cooled aeroderivative CCGT, the Kalina cycle, advanced fuel cells in CCGT efficiencies up to 70% may be achieved in the next decades.
- By enabling GTs to operate much closer to their design limits, it may be possible to significantly increase the marginal capacity of both, OCGT and CCGT systems – meaning cost savings for power producers and more electric power at lower prices for consumers.
- As next-generation turbine power plants evolve, the GTs will be required to operate at higher-pressure ratios and hotter TIT conditions that will tend to increase nitrogen oxide emissions. To conform to future air quality requirements, lower-emitting combustion technology will be required. Engineers hope to develop a prototype combustor that will reduce smog-causing nitrogen oxide emissions well below current systems. The goal is to cut emissions by 50% or more compared to state-of-the-art lean premixed GT combustors.

- And what should not to be forgotten, the best and most advanced technology cannot make good any mistakes or negligence of power plant operation and maintenance (O&M) personnel and management. High qualified power plant O&M team can produce power energy at a most competitive price even operating today's or "yesterday's, so called "standard" equipment. And therefore it should be emphasized that even the most advanced equipment can produce only average results if the provider neglects the fundamental engineering and O&M rules and on the other hand the wise and qualified provider can beat unexpected limits using "up-dated" equipment. But the combination of both, the advanced technology and experienced O&M provider can beat all records in the power generation technology.

SPEAKER's BIOGRAPHICAL SKETCH

Miro R. Susta is graduate of Swiss Federal Institute of Technology in Zurich, ETHZ; Diploma (M.Sc.) degree in Power Plant Mechanical Engineering.

He is a Member of Swiss Engineers and Architects Association (SIA) and Member of American Society of Mechanical Engineers (ASME).

Mr. Susta has more than 27 years of professional experience in power plant design & engineering, field and factory testing, sales and marketing with Sulzer-Brown Boveri Turbomachinery AG, Brown Boveri AG, Motor Columbus Consulting Engineering AG and Asea Brown Boveri AG in Switzerland.

During his professional career, Mr. Susta accumulated a vast knowledge and experience not only in power plant design, engineering, marketing and management, but also in general power business not only in Europe but also in miscellaneous countries in Asia.

In year 1992, Mr. Susta joined Swiss consulting engineering company IMTE AG, which is specialised in thermal power generation consulting engineering activities. Among others, he was involved in Lumut 1303MW CCGT power generation project in Malaysia from year 1993 till 1997.

At he present he is a director of IMTE AG Switzerland and SEA Regional Manager of IMTE AG Ltd. with office in Malaysia.

Mr. Susta is also involved in Sepang 710MW CCGT project in Malaysia