11th IGTC
Dispatchable technology & innovations for a carbon-neutral society
10-11 October 2023, Brussels, Belgium
Paper ID Number:20-IGTC23

THE EVOLVING TRANSFORMATION OF GAS-FIRED POWER PLANTS TOWARD A SUSTAINABLE AND PROFITABLE GENERATION SYSTEM

Marco Cioffi/Ansaldo Energia

Via N. Lorenzi, 8 - 16152 Genova, Italy
(+39) 010 6556682
marco.cioffi@ansaldoenergia.com

ABSTRACT

Over the next few years, the heavy-duty gas-fired power generation development roadmap is expected to include several new or upgraded capabilities: increased plant flexibility and reliability, the ability to keep revenues by promptly following the energy commodities and electricity markets, plant hybridization and operation optimization, the increasing use of non-fossil fuels, resilience to extreme weather conditions.

The paper presents the main evolution trends of gas-fired power generation in the energy transition scenario and the energy trilemma challenges. The key role of flexibility and evolution toward a future-proof power plant is then highlighted, where the use of (green) hydrogen as an alternative fuel seems to be today one of the main keywords.

Some different (but complementary) routes toward these directions are finally discussed and, for each approach, a landmark Ansaldo Energia project on new or existing gas power plant is presented. These accomplished cases are exemplary of the synergy between the Research and Development strategies and directions and the multi-decade knowledge and capability on the design, construction, and management of a large fleet of plants.

Keywords: power plant, power market, profitability, reliability, availability, product development.

INTRODUCTION

In the upcoming power grid scenario, dominated by not-programmable renewable generation, gas-fired power plants will have to meet more stringent performance requirements, environmental constraints, and updated regulations. For many decades, Ansaldo Energia (AE), as an Original Equipment Manufacturer (OEM) with a power products' large portfolio, has been implementing product development strategies aimed at assuring new and existing power plants are future-proof and sustainable while maintaining the assets' value and profitability. To achieve these goals, customers are provided with new equipment, upgrades, and solutions to allow power plants to maintain their positioning in the electricity-dispatching arena.

The International Energy Agency, in its relevant World Energy Outlook 2022 report, set a list of guidelines aimed to have a secure energy system during the “mid-transition”, when carbon-emitting and clean fuels and technologies need to co-exist (IEA, 2022b). These guidelines include:

- To manage the retirement and reuse of existing infrastructure carefully: gas-fired plants are crucial for the electricity system.
- To invest in flexibility, a new watchword for electricity security: this means to be able to provide a flexible loading up and down in fossil generation, and to couple generation with suitable storage systems.
- To foster climate resistance of energy infrastructure: this means increasing resilience toward extreme weather impact.

NOMENCLATURE

AE	Ansaldo Energia.
APEx	Ansaldo Energia Predictive Maintenance.
CCGT	Combined-Cycle Gas Turbine.
DA	Day-Ahead electricity market.
EOH	Equivalent Operating Hours.
ETN	European Turbine Network.
GHG	Greenhouse Gases.
GT	Gas Turbine.
HRSG	Heat Recovery Steam Generator.
IEA	International Energy Agency.
I&C	Instrumentation & Control
IGV	Inlet Guide Vanes.
IPS	Integrated Plant Support.
OCGT	Open-Cycle Gas Turbine

OEM Original Equipment Manufacturer.
OPC Operational Concept.
OPEX Operative Expenditures.
RES Renewable Energy Sources.
SFC Static Frequency Converter.

GAS-FIRED GENERATION EVOLUTION TRENDS

During the next years, the development roadmap of heavy-duty gas-fired power generation is expected to include several new or updated capabilities (Fig. 1):

- Increased plant flexibility and reliability. Minimum-load and part-load performance, mainly in terms of efficiency and emissions, are getting quite greater relevance, due to the actual operation profile.
- Increased revenues and reduced operation costs, by promptly following the energy commodities and electricity markets.
- The ability to stack multiple revenue streams, by fully providing grid support ancillary services.
- Plant hybridization and operation optimization, by adopting advanced energy storage solutions and even coupling with renewables (Giacchino and Repetto, 2019).
- The increasing use of non-fossil fuels, such as (green) hydrogen, e-fuels and/or biofuels.
- Resilience to extreme weather conditions. Because of their intrinsic robustness characteristics, gas-fired plants will maintain a strategic role in the security of the power system.

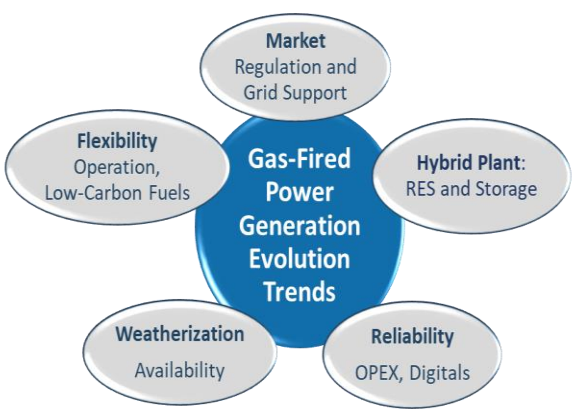

Fig. 1 - Gas-fired power generation evolution trends.

In the Ansaldo Energia vision, the near-future gas-turbine power generation systems will be able to reliably supply (or even draw) programmable active or reactive power on the grid, and fully participate in the capacity and grid balancing and regulation services market, thereby maintaining their key role in the grid support and their position in the dispatching merit order.

Transition and Energy Trilemma

One of the main topics of the power generation sector is the Energy Transition, with the transformation from fossil-based to low or zero-carbon electricity, aimed to reduce carbon emissions and to mitigate the effects of climate change.

In the pathway toward the Energy Transition, the power operators are requested to manage the competing demands of the so-called Energy Trilemma, which means balancing three different goals in the energy systems: Energy Security, Sustainability, and Affordability.

Energy Security is defined as the ability to meet current and future energy demand, considering reliability and resilience to energy or fuels supply shortages. An efficient way to improve energy security is indeed maintaining and extending the life of gas-fired energy plants during the move to net zero.

Energy Sustainability is the ability to avoid environmental degradation and reduce the impacts of climate change. The focus here for power generation is on efficiency, decarbonization, and air quality.

Energy Affordability is related to the social impact and represents the ability to provide the population with full access to energy, for both domestic and commercial users.

The sometimes-unstable balance among the different Trilemma targets can be affected by external geopolitical events, following shifts in countries' energy policy, as recently occurred in Europe (Cioffi, 2022b).

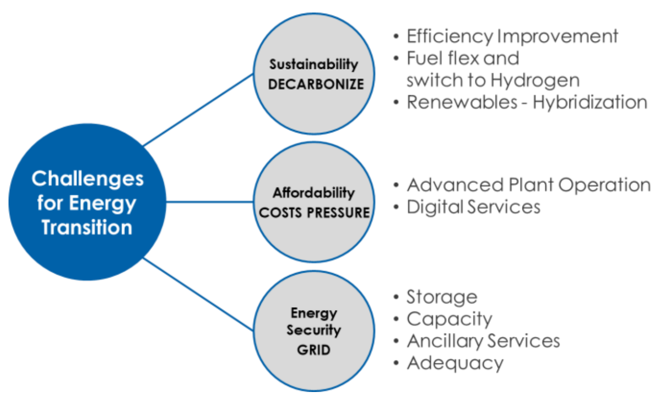

Fig. 2 - Energy Trilemma and related power generation challenges.

Power generation faces the big challenges of finding solutions to cope with each leg of the Energy Trilemma (Fig. 2). In this context, Sustainability mainly means decarbonizing gas-fired generation by efficiency improvement, fuel flexibility and switch to hydrogen, and hybridization of gas power plants with renewables. Affordability, in the volatile energy commodities markets and higher supply chain costs, can be achieved by: a) adopting tailored and advanced plant operation schemes;

b) improving digital services. Energy Security is grid support by introducing innovative storage solutions, an increase of programmable capacity, and full access to the grid and ancillary services.

Climate Resilience and Reliability

Different factors combined to drive new demand for fast-response, flexible and reliable gas-fuelled power generation: the climate trends of the past years, a mix of extreme weather events, together with the loss of grid inertia and the growing generation by intermittent sources.

During the Summer of 2022, the historical maximum temperature in England has been reached (MetOffice, 2022), even affecting the operation of fossil power plants. During the same weeks, many nuclear power plants in France were put in low-load mode by following the increased temperature of the rivers cooling water above limits (IEA, 2022a). In the same period, the Californian System Operator declared a Maintenance Operations Restriction Notice (CAISO, 2022) to avoid any outage of power assets for maintenance to deal with the surge in power load following extremely high temperatures.

In February 2023, the United States Federal Energy Regulatory Commission issued new requirements to protect power plants from very cold weather (FERC, 2023). The approved weather reliability standards are aimed to prevent a recurrence of the unprecedented power outages affecting Texas and the South-Central U.S. The standards contain new and revised requirements to advance the reliability of the grid during extremely cold weather temperatures.

The climate resilience (sometimes, called weatherization) of new and existing power assets must be therefore increased soon to keep the required system reliability.

THE KEYWORD IS FLEXIBILITY

With the increasing share of RES in the generation mix, gas turbine power plants are proven to have a relevant role in ensuring the safe operation of the electricity network, by providing the grid with some relevant services:

- on-demand and programmable power supply.
- flexible operation, from base load to peaking operation models.
- system inertia, to stabilize the grid frequency.

To profitably manage the variable electricity (and fuel) prices, which, within the day, can switch from very high to very low values or even become negative, GT power plants are required to efficiently modulate the power supply to the grid to comply with the demand and to effectively compete on the market with the other producers and the other generation technologies. The competition passes through the minimization of the plant's OPEX and the optimization of the generated power dispatchability on the local electricity market.

New operation schemes and novel plant configurations can be in addition adopted to gain advantages over the competitors and, in the end, increase the power asset profitability. The selection of the best strategy to have success in the power dispatch challenge requires the adoption of suitable market models and advanced analysis approaches.

Plants Operation and Costs

Today gas-fired power plants operate in cycling mode by following the daily dispatching profitability and by supporting grid balance. To keep their positioning in the merit order and to preserve dispatchability, both single-cycle (also known as Open-Cycle Gas Turbine OCGT) and combined-cycle GT plants must reduce operative costs (OPEX) and ensure availability and reliability (Jakoby et al., 2022).

OPEX are of course mainly related to fuel costs, where suitable long-term purchase contracts are usually an effective way to ensure natural gas supply by avoiding the spot market instabilities.

Another relevant route to keep OPEX is to ensure the plant's availability through larger maintenance intervals and optimized overhaul procedures. In the present cycling operation models, maintenance inspection schedules are indeed often constrained by the maximum allowable number of starts between hot parts inspections: a suitable optimized components design procedure by the OEMs is therefore required.

In addition, predictive maintenance digital tools, such as the APEx system by AE, can allow the optimal planning of engine overhauls.

Dispatching in the liberalized electricity market

In the liberalized energy market, electricity and grid services wholesale spot prices are determined through an auction system, where different players act: energy producers, buyers, market regulators, and Transmission System Operators. Within this market system, gas-fired power plants must be able to keep upgrading their strength and operation models, to maintain their role in the generation dispatching order.

The Day-Ahead (DA) spot market usually hosts most of the electricity sale and purchase transactions: in the DA, hourly energy blocks are auctioned for the next day. In the increasingly complex interaction inside the market among Renewable Energy Sources (RES) and gas generation, suitable auction strategies must be in addition adopted by fossil operators to maximize their profit, by fitting the local energy mix, demand curve characteristics and regulatory constraints. Market intelligence and suitable plant modelling tools are required to keep pace with the merit order (Cioffi, 2023).

The top priorities for gas-fired power plants operators on the DA market appear to be (in order of relevance):

1) **reliability** - it gives the possibility of accurate modelling and operation forecast.
2) **availability** - which means longer maintenance intervals and stable operation.
3) **low operation marginal cost** - through high efficiency (i.e., low fuel and carbon allowances cost) and larger digitalization.

FUTURE-PROOFING GAS POWER PLANTS

In the following, some different (but complementary) routes toward future-proofing the new and existing gas power plants are presented: for each approach, a related landmark AE project is presented. These landmark cases are exemplary accomplished projects, and they are the result of the synergy between the Research and Development strategies and directions and the multi-decade knowledge and capability on the design, construction, and management of a plants' large fleet.

Hydrogen-to-Power

In 2020, the European Turbine Network (ETN) issued the Hydrogen Gas Turbines Report (ETN Global, 2020). The Report states hydrogen, as a future energy vector, will redefine the role of gas turbines in a carbon-neutral energy scenario. ETN confirms gas turbine systems, as a highly efficient, well-established, and versatile technology, can facilitate the smooth transition towards a decarbonised future.

In the short-term, existing power assets and infrastructure can be used with updated gas turbine technology to drastically reduce the carbon footprint of power generation. A very fruitful way is to blend natural gas fuel with hydrogen. But, due to the hydrogen's low volumetric density, in the adopted hydrogen/natural gas mixture quite high values of hydrogen content (usually referred to as volume fraction) must be achieved to get significant CO_2 emissions reduction (Fig. 3).

Ansaldo Energia has a long experience in the management and the burning of high hydrogen content fuels, for more than 20 years (Bonzani, 2006). This experience includes the design, manufacturing, commissioning, and operation of all the systems affected by implementing hydrogen addiction; it involves the combustion system, the fuel feeding system, the auxiliaries, the safety system, and the modification of the control system software.

Grid Stability Support

The increasing contribution of RES in the power generation mix leads to an increased need for grid stability. Combined-cycle operators are called to meet this challenge, with faster start-up and frequency control, and part/minimum load operation (Cioffi et al., 2014).

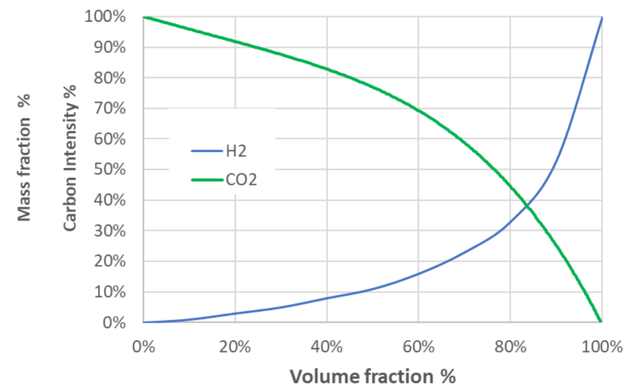

Fig. 3 - Typical relation between volume and mass percentages in methane/hydrogen mixtures, and impact in terms of CO_2 emissions.

• **Load Rate to achieve faster up and down ramps**. Specific servicing packages have been developed by AE to achieve the tasks. These include GT controller modifications on Inlet Guide Vanes (IGV), OPerational Concept (OPC) and load control functions. Special sessions of combustion tuning and parameter adjustments are required to check combustion stability and controller actions. Further load rate improvement can be obtained with the AE Autotune digital system.

• **Purge Credit**. Engineered and tailor-made solutions are available, able to achieve purge credits which are fully compliant with current international safety regulations. Existing plants can be retrofitted with additional gas valves, skid and piping adjustment, and an update of Instrumentation & Control (I&C). In such a way, the boiler purge executed during GT shutdown becomes a credit purge on start-up for up to 192 hours. This design robustness and operational flexibility save up to 17 minutes of a typical cold start-up time, leading to cost-savings and increased availability.

LANDMARK EXPERIENCE #1 - HYDROGEN PILOT PROJECT

The transition of energy systems towards sustainable scenarios is mainly based on the adoption of Greenhouse Gases (GHG) emissions reduction policies. For the power generation sector, one of the most promising strategies able to reduce the carbon footprint of gas turbine power plants and to keep the value of the existing assets is the use of fuel blends, where the natural gas is mixed with hydrogen.

Hydrogen Operation in CCGT

AE gained significant practice for more than 15 years in a Combined-Cycle Gas Turbine (CCGT) large power plant located in Southern Italy, where the customer requested to burn a recovery gas (syngas) from its refinery process, integrating it with natural gas and thus reaching a high hydrogen concentration, without nitrogen or steam addictions (Cioffi, 2022a).

Ansaldo Energia originally designed and supplied the two AE94.3A gas turbines and then all the combustor and fuel supply modifications required to allow operation with the specified syngas-natural gas mixture.

Project Timeline

The plant's initial contractual H_2 content in fuel gas was 10% in volume. Later, thanks to the excellent behaviour of the gas turbine and the refinement of the control system, the H_2 percentage was progressively increased to 15% and then, following the customer needs, up to 26% (Fig. 4).

To increase the plant's reliability and availability and to ensure a safe operation, the plant is remotely monitored by adopting digital services tools such as the AE Integrated Plant Support (IPS, Fig. 5) and Autotune (Fig. 6).

To date, the two units operate safely with a record of more than 265.000 EOH (Equivalent Operating Hours) and more than 670 starts, burning a syngas-natural gas mixture containing hydrogen between 15% and 26% vol. During 2022, the overall saving on plant CO_2 emission has been 10220 tons (Fig. 7).

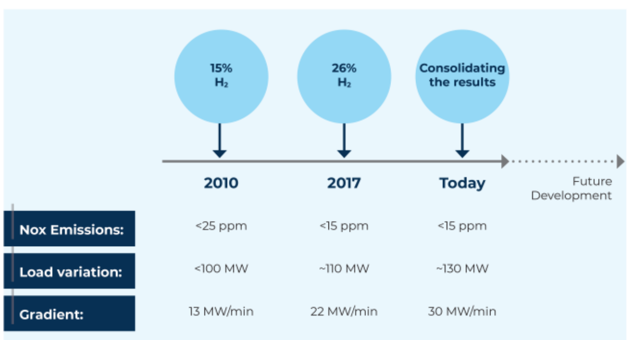

Fig. 4 - Hydrogen Pilot Project roadmap and achievements.

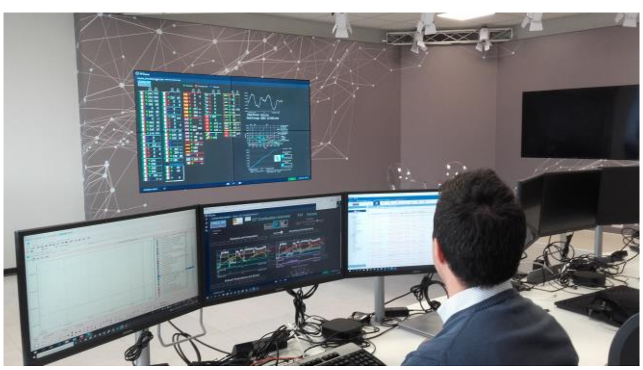

Fig. 5 - IPS control room in Genoa (I) main AE facility.

Fig. 6 - AE Integrated Plant Support and Autotune output. The online dashboard shows the actual main operative turbine parameters (e.g., active power, IGV angle, NOx emissions) and the hydrogen used in the blended fuel, as well as the saved CO_2 emissions.

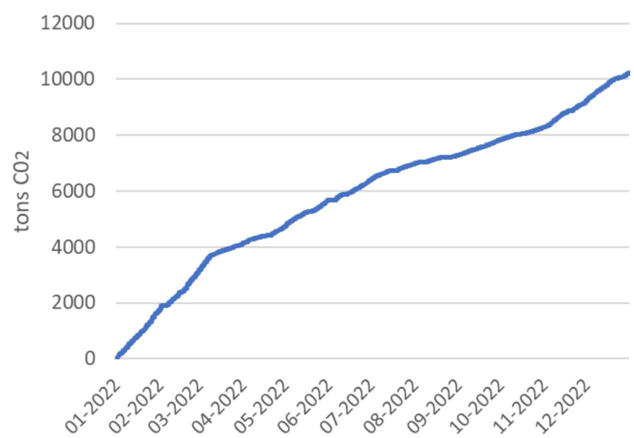

Fig. 7 - Landmark Experience power plant: 10220 tons overall saved CO_2 emission during 2022.

Additional Rig Tests

Based on the extensive experience acquired in the field, additional high-pressure combustion tests have been performed to characterize the operation of the burner with hydrogen blends ranging from 0 to 50% in volume (Fig. 8), without derating. High-pressure tests at engine conditions demonstrate flashback-free stable operation in the full range of 0 – 50%vol. H_2, without an increase in NOx emissions up to 30% vol H_2.

In addition, to support the analysis of the test results, reactive and thermoacoustic numerical simulations have been performed (Ciani et al., 2021).

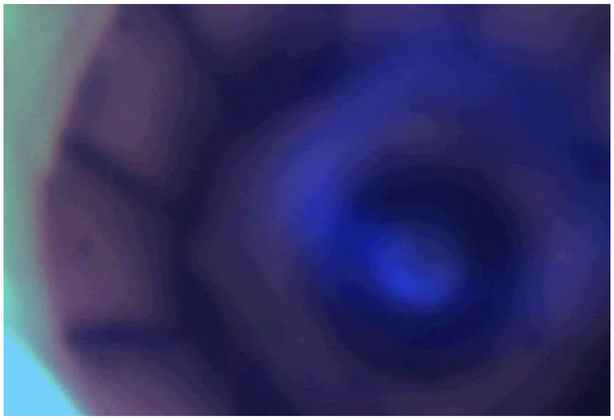

Fig. 8 - Camera-taken flame picture inside the actual GT burner for the 50%vol. hydrogen blend during a high-pressure rig test.

LANDMARK EXPERIENCE #2 - AE94.3A PEAKER

The latest developments in the EU energy market point to gas-fired plants as long-term partners for renewables, when used for extended periods, because they are essential for reliable grid balancing. In this evolving scenario, the AE94.3A gas turbine (Fig. 9) claims a key role as an optimal option for peaking power producers. Due to its open-cycle fast start and rapid load change capability (up to 45 MW/min), its contribution to grid frequency regulation is ready to use, which is important for grid stability, given the volatile supply of unprogrammable sources.

A new AE94.3A unit has been recently put in open-cycle operation in Southern Germany for a main energy company. The unit is going to operate as a peaker plant to fulfil requirements from the grid operator. The gas turbine is fired by natural gas, adopts best-in-class combustor technologies, and it is required to achieve low NOx emissions within 35 mg/Nm^3. The plant requirements include the ability of a fast start-up, to ramp up from "ready-to-start" GT condition to full Base Load within 26 minutes.

The AE94.3A light rotor and radial clearance gap optimization during transient phases result in balanced thermal distribution throughout the entire engine. When combined with extreme operating simplicity, this gives this gas turbine high cycling capability. It can be started and stopped without any time limitation, meaning that it is effectively available as often as the grid requires it. The GT can reach Base Load within 20 minutes, a key factor for grid stability and peaker plants.

With its extended time between major overhauls (up to 5 years, depending on operating conditions), the durability of hot-gas path parts and quick on-site activities, the AE94.3A has a beneficial effect on operating and maintenance costs too and it offers the most profitable solutions for peaker plants. The simple and robust design of the AE94.3A has made it possible to accommodate continuous upgrades over the years, progressively enhancing performance up to the top of F-class (above 40.3% GT ISO efficiency) while maintaining and even improving the level of reliability (more than 99.5%), thanks also to the large number of operating hours accumulated by the AE fleet (more than 4 million EOH) and feedback from the field and the customers.

Fig. 9 - The AE94.3A gas turbine.

LANDMARK EXPERIENCE #3 - GT 26 ENHANCED FLEXIBILITY PACKAGE

The MXL3 Package is the latest member in the family of modular upgrades developed by Ansaldo Energia for the GT26 gas turbine (Fig. 10). The MXL3 Package grants power plant operators the full benefits of performance, extended turndown ratio and high availability; moreover, it allows extensive operational flexibility by switching between 'performance' optimized M mode and 'maintenance cost' optimized XL mode, depending on the market requirements.

The M mode power output in combined-cycle can be increased by up to 35 MW and the efficiency by up to 1.6%. Maintenance intervals are extended by 4000 operating hours.

In XL mode, maintenance intervals are further extended up to 12000 operating hours, resulting in increased availability and a reduction of maintenance costs. The overall plant power output can be increased by up to 22 MW and the combined-cycle efficiency by up to 1.3%.

The Project

In the framework of a scheduled major inspection, Ansaldo Energia implemented the innovative MXL3 Package on a combined-cycle power plant in the Netherlands, operated in an intermediate cycling regime. With its unique increased performance, reduced CO_2 footprint and H_2 co-firing readiness, the MXL3 Package provides the plant operator with the top-level gas turbine technology to support the energy transition towards a carbon-neutral economy. These features allow the power plant operator to adapt to fluctuating market demands, enhancing output and reducing maintenance costs.

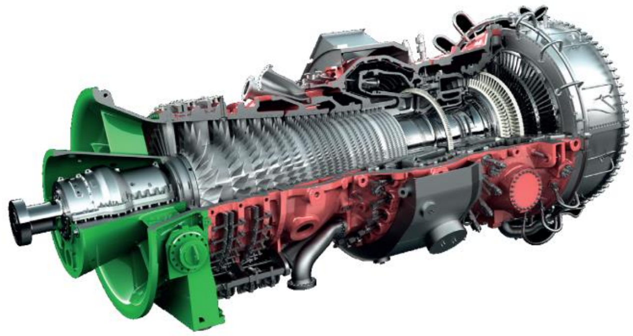

Fig. 10 - The GT26 gas turbine.

The MXL3 Package features advanced H-class technology (Fig. 11) and achieves the availability, flexibility, and performance at the upper-class turbines. This allows the power plant operator to adapt to fluctuating market demands, enhancing output and reducing maintenance costs (Jakoby et al., 2022). The increase in efficiency will result in up to 40.000 tons of CO_2 savings yearly, depending on the running profile. In addition, MXL3 technology increases fuel flexibility and allows the co-firing of hydrogen up to 45% of volume flow, with no required changes to the gas turbine hardware.

Fig. 11 - The GT26 MXL3 Package blading.

LANDMARK EXPERIENCE #4 - PLANT RENEWAL AND REPLACEMENT

Gas-fired power plant owners need a wise investment strategy to keep their facilities competitive, clean, and ready for changes in grid requirements and energy scenarios. With the gas turbine replacement, the operators are given a cost-effective option to enhance their assets and unlock the lifetime extension potential, while keeping their facilities efficient and emission compliant. At the same time, plants can improve heat rates and flexibility to better serve an expanding market during the transition. Replacing an obsolete, ageing or no longer competitive gas turbine unit with a new, more advanced version provides power plant owners with an opportunity to boost the plant's overall performance without affecting most of the existing plant equipment. The replacement of the gas turbine, therefore, gives an effective answer to the needs of gas plant operators looking to reach multiple efficiency, emissions, and capacity targets by investing sensibly in a quick and effective solution that will help them tackle whatever opportunities or challenges the energy transition may bring.

The GT replacement is the right fit for investors needing to implement an ad-hoc solution to cut energy costs and curb emissions at their facilities. Also, turbine replacements can help overcome the limitations of repairs or other remedial measures carried out on an as-needed basis, by enabling an all-around system improvement and helping keep the remaining existing equipment in good working order. Turbine replacement measures entail lower investment costs: on top of other advantages, they can facilitate access to finance for the plant improvement program, offering a higher return on investment as compared to other available options.

Far less expensive than plant dismantling and subsequent reconstruction, turbine replacement projects are more attractive in that they can usually be brought to completion within a short timeframe.

The Project

In 2017 Ansaldo Energia replaced an old gas turbine generator unit with the turnkey supply of a new AE94.2 GT (Fig. 12) serving a main chemical facility in Central Italy. The original power generation system consisted of a combined-cycle power plant, 2+1 configuration, two AE94.2 gas turbines, two HRSGs (Heat Recovery Steam Generator), and one steam turbine.

The gas turbine replacement program was based on a feasibility study developed by Ansaldo Energia, the engine manufacturer, in cooperation with the Customer. Through an in-depth and complete preparatory phase, it has been identified the solution that fitted best with the existing plant's features, the plant operator's requirements, and the specific installation setting. Retaining the main equipment foundations already in place and partially reusing existing components, thus saving time, and cutting costs, was not the only reason why the turbine replacement project stands out as an advantageous option. Cost-effectiveness and quick implementation also matched with a reduced impact on normal plant operation (projects involving multiple units can be carried one unit at a time, keeping the rest of them running) and space allocation (no additional space required for this solution, which is vital for plants that have no room for further expansion).

The upgraded plant configuration features a new GT1 unit connected to the existing HRSG, with all the steam being delivered to the chemical plant. A second old gas turbine unit GT2 is available as a cold backup unit. The scope of works of the Project included the decommissioning and the removal of the old equipment and the supply, construction, commissioning, and start-up of the AE94.2 GT with the related generator and auxiliaries. Regarding the main civil works, new foundations were built only for the gas turbine generator auxiliary skids, while the main existing equipment's pedestal was reused. Project implementation had to fulfil a set of specific requirements that included carrying out the works within a very short timeframe, in narrow or confined spaces and giving top priority to workforce safety and environmental aspects. The dissociation of the Control and Excitation/SFC (Static Frequency Converter) Systems was initially performed, removing the interconnections between the GT1 and GT2 systems to allow for the start-up of the existing Unit GT2 and its operation during the project activities carried out on Unit GT1. An optimized activities schedule was adopted to minimize the overhaul timing and reduce the off-line of the system (Table 1).

The final engine fully complied customer's requirements, constraints and targets and it overcame the guaranteed contractual performance (Table 2).

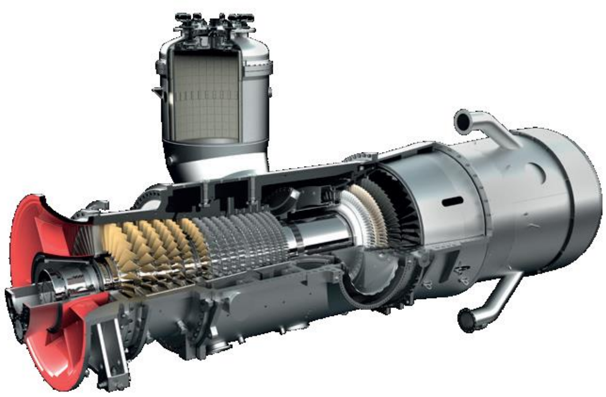

Fig. 12 - The AE94.2 gas turbine.

Table 1 - Landmark Project #4: main project milestones and achievements.

December 2016	Supply Contract and Notice to Proceed signed
September 2017	Beginning of commissioning activities
November 2017	Gas turbine first firing
January 2018	Performance Guaranteed Tests successfully performed
January 2018	Issue of Provisional Acceptance Certificate

Table 2 - Landmark Project #4: gas turbine performance after replacement.

AE94.2 Gas Turbine

Type	Ansaldo Energia AE94.2
Fuel type	Natural gas
Final Gross Electrical Power	Above guaranteed values
Final Gross Efficiency	Above guaranteed values

CONCLUSION

The target of gas-fired power generation plants is to keep providing, in the new and medium-term future, the reliable supply of programmable power to the grid, to profitably participate in the electricity market and to ensure the safe operation of the power system.

A suitable combination of advanced engine and controls upgrades, innovative operation schemes and smart fitting with storage systems will allow existing and new gas-fired power plants to keep their role in the dispatching and regulation merit order.

The OEMs, from their side, must provide the customers with updated power solutions able to fulfil the market requirements and evolving energy scenarios through the continuous development of their products.

REFERENCES

Bonzani, F., "Syngas Burner Optimization for Fuelling a Heavy-Duty Gas Turbine with Various Syngas Blends", ASME Turbo Expo 2006, GT2006-90761, Barcelona, Spain, 8–11 May, 2006.

CAISO California Independent System Operator, www.caiso.com/Documents/Emergency-Notifications-Fact-Sheet.pdf, 2022.

Ciani, A., Tay-Wo-Chong, L., Amato, A., Bertolotto, E., Spataro, G., “Hydrogen Blending into Ansaldo Energia AE94.3A Gas Turbine: High Pressure Tests, Field Experience and Modelling Considerations”, ASME Turbo Expo 2021, GT2021-58650, 7–11 June, 2021.

Cioffi, M., Piola, S., Puppo, E., Silingardi, A., Bonzani, F., "Minimum Environmental Load Reduction in Heavy Duty Gas Turbine by Bleeding Lines", ASME Turbo Expo 2014, GT2014-25438, 16-20 June, 2014.

Cioffi, M., "Operation of hydrogen fuel blends in large combined-cycle gas turbine: last ten years field experience", Proc. of World Utilities Congress, Abu Dhabi, UAE, 9-11 May, 2022.

Cioffi, M., "How is it changed our perspective of Energy Transition after the Ukrainian war?", https://www.linkedin.com/pulse/how-changed-our-perspective-energy-transition-after-ukrainian-cioffi, 5 Jun., 2022.

Cioffi, M., "Bidding Simulation in the Day-Ahead Electricity Market by a Nash-Cournot Game Theory Model", Proc. of 16th OMC Med Energy Conference and Exhibition, Ravenna, Italy, 23-25 May, 2023.

ETN Global, "ETN Hydrogen Gas Turbines Report", ETN European Turbine Network, https://etn.global/wp-content/uploads/2020/02/ETN-Hydrogen-Gas-Turbines-report.pdf, Feb., 2020.

FERC Federal Energy Regulatory Commission, Reliability Standards EOP-012-1 "Extreme Cold Weather Preparedness and Operations", https://www.govinfo.gov/content/pkg/FR-2023-03-10/pdf/2023-04875.pdf, 16 Feb., 2023.

Giacchino, A., Repetto, E., "Natural gas combined cycle power plant aggregated with battery: a flexible hybrid solution providing enhanced frequency and balancing services", Proc. of SUPEHR19 SUstainable PolyEnergy generation and HaRvesting, E3S Web of Conferences, Volume 113, https://doi.org/10.1051/e3sconf/201911302002, 2019.

International Energy Agency, "France Electricity Security Policy", https://www.iea.org/articles/france-electricity-security-policy, 30 June, 2022.

International Energy Agency, “World Energy Outlook 2022”, https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A), October, 2022.

Jakoby, R., Rinn, J., Appel, C., Studerus, A., "Turn-Down Capability of Ansaldo Energia's GT26", J. Eng. Gas Turbines Power, 144(3), March 2022.

MetOffice, "Record high temperatures verified", https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/record-high-temperatures-verified, 28 July, 2022.