The Future of Gas Turbine Technology
7th International Gas Turbine Conference
14-15 October 2014, Brussels, Belgium

Paper ID Number (*30)*

HEAVY DUTY GAS TURBINE FLEXIBILITY: SOLUTIONS, FIELD EXPERIENCES AND NEXT STEPS

Sergio Chiesi - Ansaldo Energia
Ansaldo Energia
Service Department – Fleet Management
Via N. Lorenzi, 8
16152 Genova
sergio.chiesi@aen.ansaldo.it
Mob: 0039 334 6999629
Tel: 0039 010 655 7155

ABSTRACT

Heavy duty gas turbines, originally designed for base load operation, are now requested to cover a high load range in a reliable way with faster gradients and stronger capability to reach a very low minimum environmental load within strict emission limits.

Therefore Ansaldo Energia has developed some gas turbine hardware and software modifications, in order to reach the main goals in terms of flexibility.

Main solutions actually available in order to increase gas turbine flexibility are:

a) Turndown load
reduction of the MEL (i.e. Minimum Environmental Load) with the engine still within emission limits through:
- anti icing operation and cooling valves control optimization
- regulating blow-off valves
- CO catalyst

It would be possible to reach a MEL of 30% BL (i.e. Base Load) ISO conditions.

b) Load gradients
an increase in load gradients through:
- modifications on pilot and air control
- on-site test campaign, combustion optimization

c) Power augmentation
- fogging
- IGV extra-opening
- cooling valves and OTC control optimization

d) Startup time reduction
- GT cold load gradient and start sequence optimization
- GT Fly-Restart
- purge credit

Lower turn down load and higher load gradients mean increased potential risk of combustion instability, due to the higher stress on burners. For this reason certain equipments and strong modifications on the GT controller are requested in order to guarantee the highest reliability and the most precise control of air and fuel during all the operating conditions; the last GT controller configuration helps to have same stability and performances for every type of fuel and environmental conditions.

All the above mentioned modifications have already been implemented in lot of plants both as a retrofit and as new upgraded design.

Some further improvements are under testing; secondary air savings and various kind of burners have been tested in a first campaign on an Italian power plant, while new GT control philosophy is under testing, taking into account the integration of FFT analysis instrumentation inside the fuel/air controller, in order to obtain an active control on combustion by using stability parameters.

With all these improvements Ansaldo Energia is able to offer tailor-made flexibility solutions to customers with different requests in different market scenarios.

1. MARKET SCENARIO

In the last years, deep changes due to the liberalizations of energy and fuel markets, local and international restrictions about emissions and the growth of renewables, lead energy producers to search for different requirements and performance, not only in terms of power output, but in terms of flexibility, rangeability and reliability.
Therefore the main items where customers ask Ansaldo Energia to focus on are:

- Turndown minimum environmental load, to save fuel, reduce stress on the machinery and to be more attractive in the MSD market
- Load gradients, to increase secondary reserve and satisfy grid code requirements
- Power augmentation, to increase plant capacity and cover peak demands
- Startup time reduction, to catch market opportunities and reduce start-up costs and emissions

In this new scenario Ansaldo Energia, with its OEM experience, has developed some gas turbine operating method, modifications and upgrades fully retrofittable on the existing Heavy Duty Ansaldo Energia gas turbines fleet.
All the modifications that will be mentioned in the following chapters have already been implemented in lot of plants both as a retrofit and as new upgraded design.

2. TURNDOWN LOAD

The main limitation of minimum environmental load on Ansaldo Energia Gas Turbines, using low NOx emission burners, is the Carbon Monoxide content in the exhaust.
It is possible to reduce the CO content in exhaust, and thus the minimum environmental load, by operating in two different strategies:

→ Decrease CO production by increasing combustion chamber temperature: Carbon Monoxide production is favoured in low temperature ambient, since the second combustion reaction is helped by high temperature:

$$C + 1/2O_2 \rightarrow CO$$
$$CO + 1/2O_2 \rightarrow CO_2$$

Combustion chamber temperature increment is achievable by reducing combustion air flow to the burners, in order to contain the air excess on the flame. To reduce the combustion air flow, once reached the minimum Inlet Guide Vane (IGV) position, several strategies have been identified:

- Increasing air inlet temperature by using external anti-icing system;
- Increasing air inlet temperature and reducing air flow to the combustion chamber by using bleeding anti-icing system;
- Reducing air flow to the combustion chamber by opening turbine vanes cooling air valves up to 100% position;
- Reducing air flow to the combustion chamber by opening blow-off valves up to 100% position.

→ Facilitate the CO to CO_2 conversion in the exhaust by using catalytic materials able to activate the second combustion reaction even in low stream temperature.
To facilitate the CO to CO_2 conversion in the exhaust flow, it is necessary to install, along the exhaust path, a catalytic converter able to activate the reaction even when the exhaust temperature is lower than the activation temperature.
The impact of this solution on MEL reduction and on GT and Combined Cycle efficiency has been investigated; since the CO catalyst allows reaching conversion efficiency up to 95-98%, after its installation the GT can be driven at very low load, in a range where Inlet Guide Vanes are at the minimum position.
In this case, therefore, every increase/decrease of GT load is obtained only by adjusting gas flow rate, in condition of steady air flow rate, and then it leads to an important temperature gradient on materials. Checks and calculations have been performed in order to verify that these temperature gradients were sustainable unless impact on materials safety.
Several test campaign have been carried out in order to evaluate the contribution to MEL reduction achievable by each single technology, and to estimate the relative consequence on Gas Turbine and on Combined Cycle efficiency. The experimental results obtained are presented in the following.

Anti icing operation and air flow to combustion chamber optimization

The CO formation mechanism is a function of the inlet air mass flow. As a consequence during hot seasons, when the combustion air mass flow is lower than in cold seasons, while the maximum load decrease causes to a poorer combustion, the minimum power output reachable in according to the emission restrictions slips down.
It is also possible to use the anti-icing system as a method to increase the compressor inlet temperature, even if the conditions for icing formation are not present.

There are basically two possible configurations of anti icing operating, depending on the plant design and, in particular, on the gas turbine anti icing system that is installed on the air intake:

- Standard compressor bleed anti-icing: the CO emissions containment is facilitated both by the higher compressor inlet temperature and by the loss of primary compressed air at compressor discharge, recirculated at the intake and moved away from the combustion chamber;
- External heat exchanger: an external subsystem must be installed in the plant, as a GT auxiliary; a certain amount of low pressure steam is used to heat glicolate water that is fed to the air intake through a dedicated piping. In this case the CO emissions containment is reached only by the higher compressor inlet temperature.

With both configurations it is possible to reach up to 10MW of MEL reduction, depending on the boundary conditions.

Despite different boundary conditions, especially in terms of ambient temperature, carry out different results in terms of MEL reduction, the coefficient ΔMW/ Δ°C is repeatable enough to suppose common combustion behaviour.

Likewise, in addition to the anti icing operation, there is the possibility to reduce combustion air from the combustion chamber also through the turbine vanes cooling pipes. In order to do that, the operating set point of the cooling valves (GV2 and GV3) can be regulated as a function of the load, in order to maintain valves opened with the GT at minimum load, and close them until the minimum allowed position in case of load increase.

The impact on MEL reduction of this solution is lower than the previous ones (about 3 MW), but the advantage in this case is the very low starting cost.

An alternative method to subtract air to the combustion chamber has been tested fully opening blow off valves. Besides standard machine instrumentation, additional probes have been installed to monitor GT behaviour during new operative conditions in particular blow off line and compressor stages downstream the bleeding section have been equipped with instrumentation.

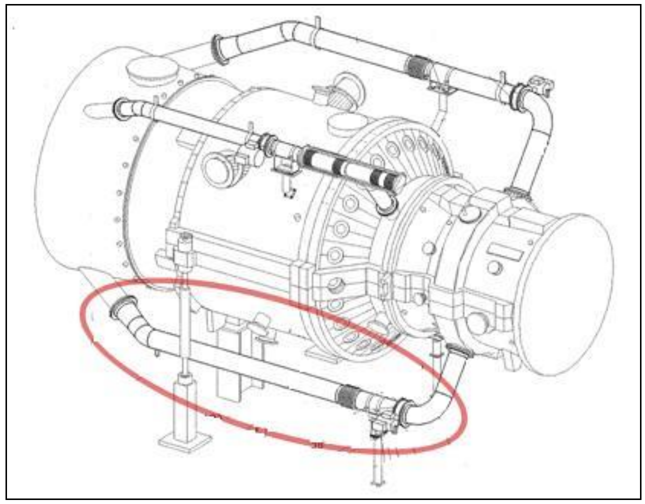

Fig. 1: Blow Off line (5th stage highlighted)

Preliminary operating tests with the BO opening at MEL have been performed by inhibiting the standard closure of the two 5th stage BO valves during start-up before achieving the nominal rotation speed (FSNL: Full Speed No Load condition).

The comparison between minimum output GT power achievable with the BO valves closed and opened is referred to a similar level of CO concentration in the exhaust gas, and it pointed out the GT MEL reduction up to 15 MW.

Each test campaign finalised to reduce MEL through combustion chamber air subtraction has been carried out using low emission NOx burners.

CO Catalyst

Another efficient possibility to reduce CO emissions in the atmosphere is CO to CO2 catalytic conversion, if the boiler design allows the catalyst structure installation.

The efficiency of the CO catalyst could overcome 98% and the maintenance interval between panels replacement could be from 5 to 7 years, depending on load operating profiles.

The minimum environmental load achievable with CO catalyst installation is lower than 27% of the maximum power output, within emissions limits (NOx < 30 mg/Nm3; CO < 30 mg/Nm3).

Several test campaigns were carried out on a AE 94.3 A4 Gas Turbine in order to evaluate the CO catalyst contribution and compare it with the contribution of the compressor bleed anti-icing. An additional test campaign was performed to evaluate the combined contribution of both CO catalyst and anti-icing system.

The combined use of different systems allows reaching a very low load (up to 25% of Maximum normalised power output) with an evident effect also on GT efficiency.

With such a Minimum Environmental Load, the gas turbine must operate within a load range at closed IGV,

with consequent mechanical and thermal stresses induced by fast gradients.
Nevertheless it has been demonstrated that this stress is lower than the stress due to a normal start up in cold conditions; so the gas turbine can be operated over the full extended load range in compliance with the grid requirements, in terms of load gradient variations.

3. LOAD GRADIENTS

An important feature of the Gas Turbine AE94.3A in terms of "flexibility" is the possibility to operate at various load gradients.
The following load gradients are installed on the last version of gas turbines of Ansaldo Energia fleet, operated in combined cycle:

- From power on to the first hour of flame (GT cold) Gradient nominal 13MW/min
- After the first hour from synchronization (GT warm) the fast gradient is activated (mainly for primary/secondary frequency control):
  - ✓ 26MW/min from minimum environmental load to 95% IGV
  - ✓ 20MW/min from 95% of IGV to Cold base load
  - ✓ 6MW/min from Cold to Hot base load.

Thanks to the development of more reactive protection logics, that prevent strong flame instability during quick ramps, together with modifications on the IGV controller and additional counters for monitoring the stress on the blades and vanes, Ansaldo Energia can safely improve the gradients in the gas turbine fleet.
The gradient of 13MW/min has already been tested for “cold” gas turbine as well. The complete loading ramp analysis on the GT with 13MW/min has been carried out, with the aim to satisfy both the requirements of the machine life (fatigue cycle checked) and on the gap state during the transition (to avoid creeping).
Such cold gradient has already been released, but in standard combined cycle configuration with no by-pass boiler stack, the maximum allowed gradient is lower, due to boiler stresses limitations.
With this “cold” gradient together with Purge credit solution (explained later), it is possible to reach base load in 30 minutes from the start up command.
It is now on going a calculation of a loading ramp of 26MW/min from “cold” conditions, between minimum environmental load and 95% IGV, in order to gain the possibility to satisfy grid support requirements since the first hour.
Ramps over 30 MW/min have been tested with the aim to have faster gradient but the same reliability; especially with strong gradient a particular attention is focused on combustion stability, during fast and extended variations. There is a closed relation between humming prevention and higher load gradients, so the update of gradients is based on a new release of gas turbine controller that includes auto-tuning function.

4. POWER AUGMENTATION

In order to increase plant capacity and cover peak demands, power augmentation is still an important item for energy producers.
As well as the increase of the compressor inlet temperature produces a better MEL, a decrease of the same parameter is a useful option to enhance the power output and efficiency of Gas Turbines at Base Load.
One of the most effective solutions that Ansaldo Energia adopts to reach this target is the fogging system.
The inlet fogger system is an active spraying system that directly sprays water into the inlet air. In this way it creates a large evaporative surface area by atomising the supply water into billions of extra-small droplets. The injected atomized water is produced by suitable injection spray nozzles located in the filter house, downstream the inlet air filters.
In terms of performances, the experience on Ansaldo Energia fleet says that an increasing of power output of 25 MW in reachable, depending on ambient conditions.
Other improvements in optimization of maximum GT load are carried out by implementation of IGV extra-opening, cooling valves GV2 and GV3 optimization at base load, and increasing of OTC ISO set point, that all together carry out an increasing of power output greater than 6 MW.

5. STARTUP TIME REDUCTION

In a market scenario in which gas turbines operation was mainly base load mode, the importance of startup time was not determinant as it is in nowadays scenario.
Customers ask Ansaldo Energia to reduce startup time to be more attractive to the grid dispatcher, and Ansaldo Energia has developed some solutions, from optimizations in the GT start sequence steps, to hardware and software upgrades.
The benefits of faster load gradients to reach the MEL have been described in a previous section; a 13 MW/min gradient, instead of 6 MW/min, allow reducing the time to reach the MEL from Full Speed No Load of about 8-10 minutes.

<u>GT Fly-Restart</u>

In case of spurious events that cause the shutdown or the trip of the gas turbine, it’s important to reduce the time loss in respect to production plans, and reduce the time interval between the event and the restart.

Thanks to this upgrade it is possible, if all startup condition has been restored, to move up the beginning of startup sequence before turning gear clutching, avoiding in this way the wait time for the completion of the GT coast down.

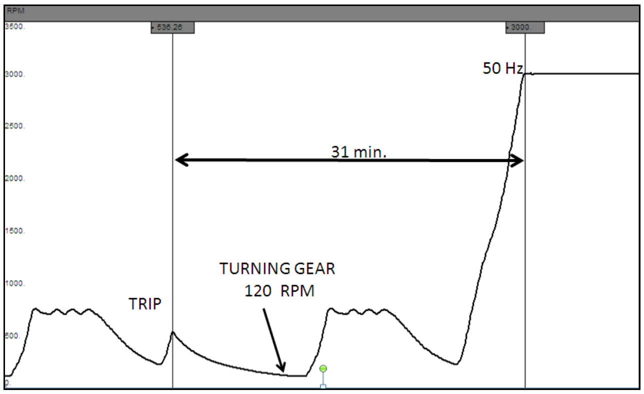

Fig. 2: GT normal restart after trip

With this implementation it is estimated to reduce the unit restart time of about 10 minutes.
In the figures 2 and 3 are shown two case of similar trip, the first with normal start after waiting turning gear clutching, the second with the selection of the Fly Restart mode.

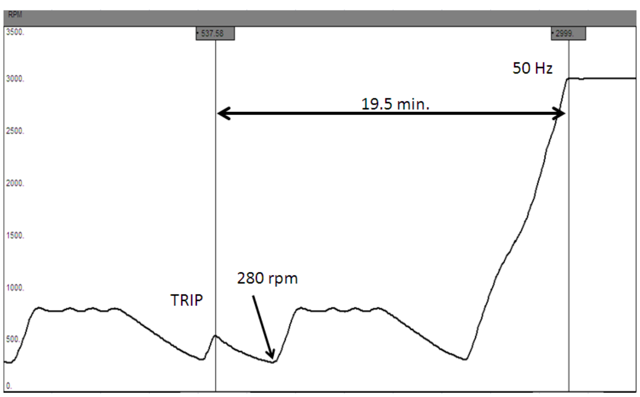

Fig. 3: GT Fly Restart

<u>Purge credit</u>

Due to the market request to have short time of starting, flexibility in use of power plant and frequent starting-stopping of the machines, the purge credit procedure could be a solution for both new and existing combined cycles.
The accumulation of vapours and liquids in the gas turbine and in the heat recovery steam generator (HRSG) system during a shutdown can combust during unit start-up and in extreme rare situations they can cause explosions and fires in a combined cycle. In order to avoid this risk, the equipment purging with ambient air to displace residual combustible gases before starting is a normal safety practice.
During a start up of a combined cycle, it's necessary to spend time to purge the gas turbine and the HRSG. As long as the temperature of the incoming purge air is less than the saturation temperature of the high-pressure steam system, the HRSG system loses heat with the effect that the super-heater panels work as large condensers for the trapped condensed steam. This condensate must be removed prior to loading the steam turbine to avoid water transport: more is the condensate, more time is necessary to start.
The purge credit is a purging airflow to remove any residual combustible materials from the GT and HRSG system during power plant shutdown rather than during start-up phase; in this way a start purge is not required with the beneficial effect to reduce the start up time.
Another tangible benefit is higher HRSG reliability and longevity. Daily cycling a combined cycle plant means more than 200 starts per year. The purge credit reduces the fatigue, due a lower condensate production caused by unnecessary cold air purges and consequent thermal damage. An additional consequence of this purging is the reduction of water consumption.
After a purge credit sequence, to guarantee the isolation between GT, HRSG and fuel supplies (gas and liquid fuels) until the next start-up, in according on NFPA 85, a double block valve and vent piping arrangement are required. The two block valves provide a positive isolation and the vent between them allows gas to escape the isolated section. In other words, for implementing a purge credit, a triple block and vent valve arrangement are required.

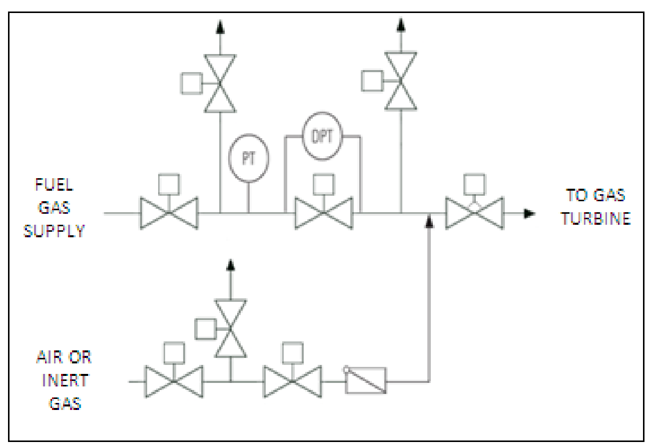

Fig. 4: Triple block and vent valves solution

The standard solution proposed by Ansaldo Energia for fuel gas is a triple block and vent valves with pressurized pipe sections. The two pipe sections are filled with an inert gas or air at sufficient pressure to prevent fuel gas from entering. Continuous monitoring of valve positions and pressurized pipe section pressures is required.

A special solution, a pre-assembled package, is proposed for operating power plants. This in order to require a very short time for the system upgrading and commissioning and really minimum modification on the existing structure.
In hot start conditions, implementation of purge credit can save up to 20 minutes off normal start-load times. Part of the time saving is the removal of the purge time itself, and the rest is faster ramp rates due to a higher initial temperature and pressure in the HRSG.

6. CONCLUSIONS

The solutions presented above demonstrate the capability of Ansaldo Energia in following the customer necessities permitting to exploit opportunities and to get profit even in a period of market stagnation by increasing the flexibility of the combined power plant.
Nowadays it is very important to have the possibility of providing to the grid dispatcher ancillary services rather than to produce a very high power with lower flexibility and Ansaldo Energia has fully anticipated this tendency by developing dedicated solutions.
According to economic convenience the implementation of the flexibility packages allow the customer the choice to stay on the grid at very low load by reducing the turndown load or to shut down the power plant and to start quickly thanks to the reduction of the start up time, comprising the purge credit solutions and to the enhanced load gradients. In both the cases there is the double advantage for the customer of reducing the fuel consumption and to catch opportunities in case of sudden requirement of power.

NOMENCLATURE

BL – Base Load

BO – Blow Off

CO – Carbon Monoxide

FFT – Fast Fourier Transform

FSNL – Full Speed No Load

GT – Gas Turbine

GV2/GV3 – Turbine stage 2/3 cooling valves

IGV – Inlet Guide Vane

HRSG – Heat Recovery Steam Generator

MEL – Minimum Environmental Load

NOx – Nitrogen Oxide