Air cooling for gas turbines

Water chillers and electrical gain during summer season

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Abstract

Gas turbine inlet air cooling is a technology designed to increase gas turbine power output. That system can lead to substantial power gain along with significant reductions in heat rate at a fraction of the cost of new power equipment. The payback can be very short particularly for high capacities and in hot climate.

This technology has been described in the ASME-ASHRAE documents. Current combined cycles recover heat from gas turbines exhaust gases up to 100°C and therefore feeding of absorption chillers would be provided by the last stages of the steam turbine, which however would reduce its capacity. Currently, the best solution is using a high-capacity and high-efficiency electric centrifugal chillers, which are convenient due to their specific price, energy consumption, weight and dimensions, modern controls, and evaporative tower performances.

Introduction

The ASME (American Society of Mechanical Engineers) “GT250” document (1990) describes the available technological and energetic solutions aimed at increasing the electric power of gas turbines, in hot ambient temperatures and due to the laws of physics, the decrease of inlet air mass flow reduces fuel consumption and therefore also electricity generation.

In summer, together with the above reduction, there is an increase of the electric power needed by air conditioners (that are used to ensure comfort of building occupants): as a consequence of power reduction, the installation of further operational gas turbines is necessary.

The above situation can be solved by using a refrigerated water coil installed on the air inlet of the gas turbine: this additional heat exchange, even with a large exchange surface, causes a slight air pressure drop. To eliminate this drop in winter, the coil (split in two halves and after disassembling the flanges from the valves) can be placed upon rails and moved aside. Electric saving could be achieved by spraying some water on the gas turbine inlet, so as to reduce the sensible temperature of air at its maximum humidity (as it happens in evaporative towers). The result is limited in humid areas and considerable in dry areas, where, however, refilling water is not easily available and expensive. A better solution for the problem can be found by examining the most convenient compromise (i.e. the most favourable cost/benefit ratio) by means of thermodynamic/economic analyses included in different articles and reports: starting from the ASME/IGTI congress held in Bournemouth in February 1993 “Maximum energy from biggest gas turbines” AICARR/CDA journal of April 2007.

In small and mid-sized electric power plants, apart from other possible applications, thermal cogeneration of exhaust gases can be used in order to feed single stage absorption chillers; this is a low cost solution (only electric consumption of evaporator/coil pumps and of condenser/cooling tower pumps) and the pay-back time is also very short (**Figure 1**).

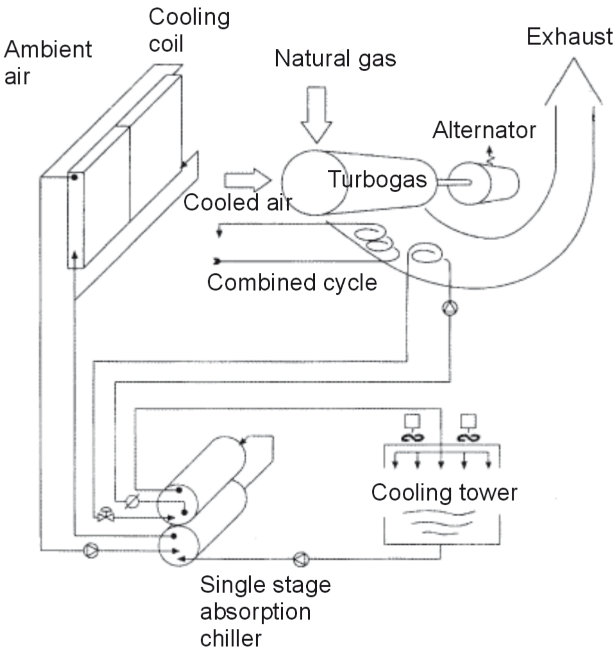

Figure 1. Turbogas air colling system with apsorption chiller in co-generation (downstream combined cycle).

Large power plants use high capacity combined cycles - gas/steam turbines up to (340+190=) 530 MWe with 15°C inlet air (ISO conditions) - and the remaining thermal recovery from exhaust gases is not sufficient. Another system may be recommended: high capacity and efficiency centrifugal chillers, resulting in a low electric consumption to be deducted from the extra production mentioned in the title of this article.

For a better analysis of this project, **Figure 2** shows a Cartesian diagram comparing ambient temperatures and operation hours throughout the year. The diagram covers the European and Mediterranean area (i.e. temperature above 10°C and up to 38°C) during the temperate and warm periods (5760 hours in total). In order to reduce the costs of an oversize chiller, a reduction of air temperature down to 20°C may be considered as satisfying for the last 760 hours; the remaining area of the diagram assumes the product "°C x h", i.e. an energy-like figure of 45000 to 49000, depending on the local climate. This thermal exchange value is multiplied by the gas turbine power as well as by its sensitivity factor, and the result represents the incremental percentage for each single °C decrease of inlet air temperature. By taking as a reference the intermediate value of 47000 °Ch, we can choose the most efficient gas turbines available on the market: 40 MW (aero derivative turbines) and 250 MW (frame-type turbines), which offer the excellent performance values of 0.4 and respectively almost 0.6; in addition with sensitivity factors of +1.4% and +0.7%.

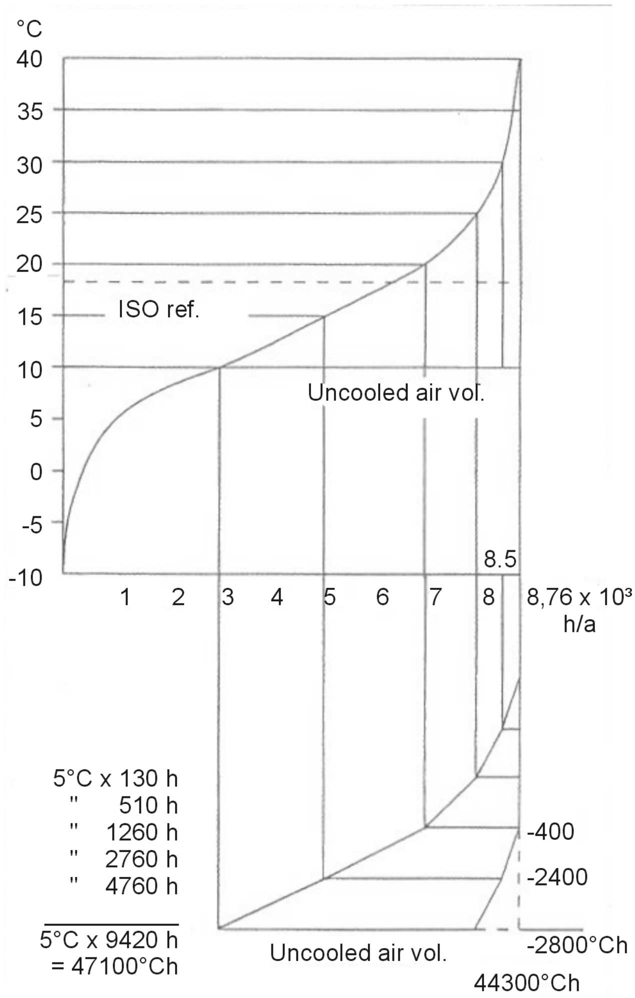

Figure 2. Outside temperature diagram (source: ENEL).

The above examples show a yearly extra electric production of (40 x 1.4% x 47000=) 26320 MWh and (250 x 0.7 x 47000=) 82250 MWh. If dividing these values by 0.4 and respectively by 0.6, we obtain natural gas consumption values of 65800 and 137080 MWh. Considering a lower calorific value of 9.59 kWh/scm, we obtain 6861300 and respectively 14294000 standard cubic metres (at 15°C). Assuming - for these gas turbines - a gas cost of 0.2 Euro/scm, as well as an electricity selling price of 0,075 Euro/kWh, costs for gas will be 1,372,260 and 2,858,800 Euro, against gross profits of 1,974,000 and 6,168,750 Euro: that's to say, 1.44 and respectively 2.16 times higher, if cooling weren't affected by the additional load of chillers and related pumps.

Consequently, it is necessary to make a realistic balance, by choosing centrifugal water chillers units in the range of 10/5°C up to 20/15°C (evaporator in/out) for temperate to warm ambient conditions, and - likewise- by choosing condensing water in the range of 25/20°C up to 38/32°C (cooling tower in/out), always when the air ambient temperature is varying. According to proven experience, the recommended cooling capacity is about 6% of the gas turbine electric power; consequently, the said centrifugal chillers would be 2.4 and 15 MW at ARI standard conditions. In order to better understand this innovation, we can choose the most complex system, including two chillers (7.5 MW each) with parallel water flow - see point 12 at **Figure 3**.

Both sketches have been traced on the same axes, i.e. ambient temperatures per running hour; let's say in a calculation range of 11 to 38°C and 240 to 6000 running hours.

Figure 3 shows air enthalpy (°C together with 100% to 40% humidity), i.e. kcal/kg; consequently, the temperature of chilled water in the coil determines the cooled air in the gas turbine. **Figure 4** follows the cooling cycle thermodynamic law in order to produce the chilled water according to the condensing water depending on weather conditions. The first centrifugal chiller starts at point no. 1, with 15-20% of its load at about 12°C am-

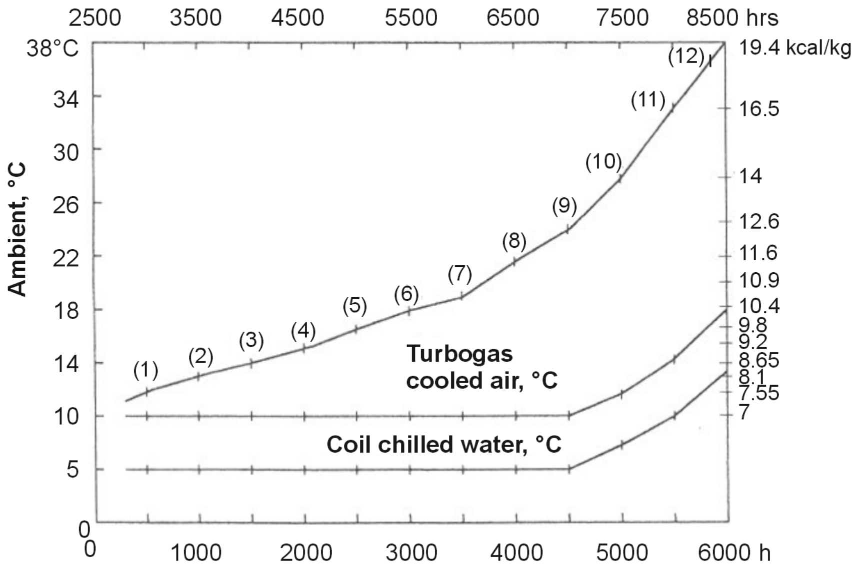

Figure 3. Chilled water/ cooled ambient air comparison.

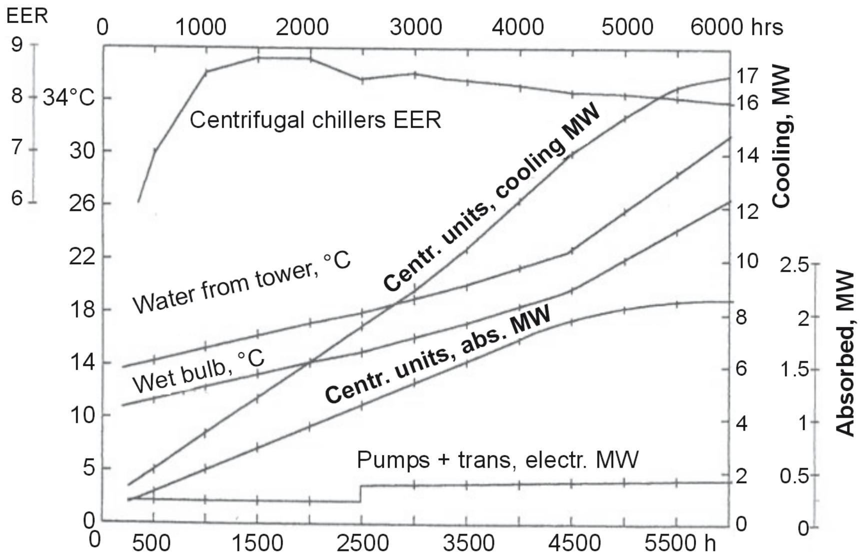

Figure 4. Cooling plant – comparison data.

bient, operating up to 100% capacity (50% of system capacity) at an outer temperature over 18°C. The other centrifugal chiller starts from point 6 in order deal with the load increase, what determines (after point 9 and up to point 12) inlet of air with temperature over 10°C. The cooling power line varies from 2 to 17 MW with an absorbed electric power of 0.25 to 2.17 MW, since the average COP is around 8. This balance varies from the favourable conditions of the condenser and the unfavourable conditions of the evaporator; the situation is reversed when ambient temperature increases.

Integrating the cooling and electricity areas, a rough calculation shows 50,000 and 6,250 MWh during 5760 hours per year. For the two pumps of each centrifugal chiller, we assess 0.2 MW up to point 5, and 0.4 MW up to point 12; through an optimization of the inverters we should obtain a consumption of 1,750 MWh. For this reason, net electric production is reduced to (82,250-6,250-1,750=) 74,250 MWh, corresponding to 5,568,750 Euro per year (given 0.075 Euro/kWh). The final difference - if compared to the gas cost of 2,858,000 - is a gain of 2,710,750 Euro, which is far higher than the preliminary financial charge of this system, which is suitable to improve performances: an attractive pay-back time! However, each single case must be dealt with and verified according to its specific features. 3E