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Achieving Optimal Economic Benefit from Air Inlet Cooling

BY STEPHEN GREEN, JOHNSON CONTROLS

Gas turbines have been widely deployed in industrial applications for decades and are used to produce the power to drive propellers, pumps and compressors. In particular, gas turbines are favored by utilities and generating companies in the power generation and electricity sector for their economics, and also because they are considered the cleanest means to generate base load power when firing natural gas compared to coal or oil based fuels.

As a gas turbine is a constant or fixed air flow volume machine, the density of the air volume flowing into to the machine is influenced by factors such as altitude, relative humidity and ambient temperature. Of the three, ambient temperature is the most influential in determining the performance of the turbine. Gas turbines are designed to have their 'rated' performance at what is termed 'ISO Conditions', which are 15°C, 60% Relative Humidity at sea level. When deployed in hotter and more humid locations, relative to the ISO condition and where the air is of a lower density, this results in lower gas turbine power output and fuel efficiency. This can be in excess of 30% and 5% respectively when compared to operating in more temperate ISO Condition environments and is a costly consequence to owners of gas turbines operation in high ambient temperature environments.

In higher temperature environments, cooling the ambient air entering the gas turbine can negate the performance degradation, providing additional capacity to sell whilst reducing the fuel cost required for each unit of electrical energy produced, hence improving the economics of gas turbine operations significantly.

As power generation is a highly competitive industry, utilities, generating companies and ndependent power plant (IPP) developers face ever-increasing demands to meet growing load demand requirements at more competitive tariff levels. This has driven growing interest in the application of Gas Turbine Inlet Air Cooling (GTIAC) as a solution to maximize the earning potential of generating assets in tropical regions.

The subject of GTIAC application to gas turbine performance has been well covered in industry papers and conferences, however, less so the considerations for optimization of the GTIAC system itself.

GAS TURBINE INLET AIR COOLING

There are generally two main approaches to Gas Turbine Inlet Air Cooling (GTIAC) available on the market: 'wet' evaporative or fogging based, and mechanical based solutions. The principle considerations of the 'wet' based technologies are their limited effectiveness in higher humidity conditions as these systems require a continuous supply of demineralized water which is not always available or permissible. In addition, extreme care needs to be exercised with regards to the quality

The GTIAC system installed at Navanakorn Electric Co's 120-MW CCGT Cogen facility in Thailand utilizes chiller plant. Photo courtesy: Johnson Controls of the water used in 'wet' systems to prevent mineral build-up on compressor blades. This could potentially lead to gas-path corrosion caused by dissolved minerals present in water which can add significantly to maintenance costs, or in extreme cases even cause the failure of the gas turbine.

Mechanical chilling, based on proven water-chiller and heat-exchanger technologies, delivers the cooling capacity required, dependability and consistency, to obtain optimal performance from the gas turbine. Johnson Controls (JCI) has over 100 years of experience in the industrial cooling and refrigeration sector and our chillers have formed the core of GTIAC systems for over twenty years, applied in power plants across the globe including Asia, Africa, the Middle East and the Americas.

With growing interest in GTIAC system deployment, we see an increasing number of client enquiries on systems which have not been considered holistically. The result can be a suboptimal GTIAC system which consumes more parasitic load, which delivers lower economic value, and takes up more precious site space than should be necessary.

To determine the design conditions for the GTIAC system, we need to consider the desired 'cooling set point', the duty required of the gas turbine, and the average and 'worst case' ambient conditions to arrive at the cooling capacity required to be transferred to the airstream. The 'cooling set point' or optimal gas turbine compressor entry air temperature is generally determined by the economic analysis of how much augmented capacity can be sold profitably, net of operating costs, including the parasitic load of the chiller plant. A commonly applied cooling set point is 15 °C, which is the coincident dry bulb temperature of the gas turbine ISO rating. However, this may not necessarily be the optimal set point. In high humidity environments consideration needs to be given to the level of 'sensible' cooling that is economically optimal as opposed to expending amounts of the chilling system energy on the production of condensation from the humid airflow.

Once the design condition has been set and the cooling capacity to be transferred to the air stream has been calculated, the design of the air to water heat exchangers and the cooling coils will determine the chilled water volumetric flow rate, the delivery and return water temperatures to be produced by the chilling system.

This is where the most common design flaw occurs in the overall GTIAC system design. In many cases, the design and supply responsibility for the air stream cooling coils, mounted in the gas turbine inlet air filter housing, and the chiller system lies with separate vendors. This results in a GTIAC system that has not been considered holistically in terms of optimal through life performance.

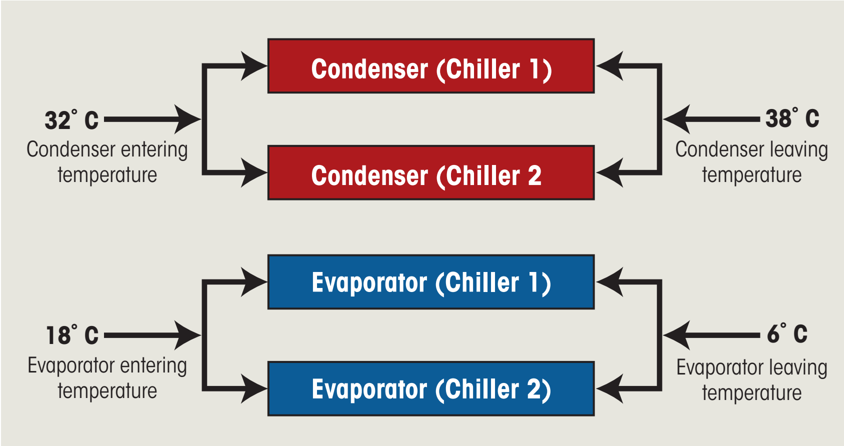
COOLING COIL DESIGN AND SELECTION

If the cooling coils are selected with first cost and air pressure drop metrics – ignoring the performance of the chiller plant – the smallest heat transfer surface produces the least expensive heat exchange coil. As the cooling system capacity is determined by the gas turbine combustion air mass flow, cooling set point and ambient conditions, minimizing the cooling coil heat transfer area maximizes the logarithmic mean temperature difference (LMTD) across the cooling coils in order to maintain the fixed cooling capacity.

In this situation, a low chilled water delivery temperature and small delta T (the temperature rise between the delivery and return chilling water flow) is necessary for maintaining a high LMTD across the cooling coils, where there is limited heat transfer surface. A chilled water temperature of 10°C or more below the gas turbine inlet air set point and chilled water delta T below 7°C is necessary to maintain this high LMTD across the cooling coils.

On the other hand, if the cooling coils are selected taking into consideration their impact on the chiller plant performance, a significant improvement in the overall GTIAC system efficiency can be achieved. Increasing the chilled water delivery temperature and chilled water delta T will have a very positive impact on the parasitic load of the balance of plant equipment in the GTIAC system. The higher chilled water supply temperature will increase the evaporative pressure in the chiller's evaporator and consequently reduce the compressor pressure ratio. A smaller pressure ratio results in lower electrical consumption of the compressor motor, which means better chiller efficiency and lower heat rejection from

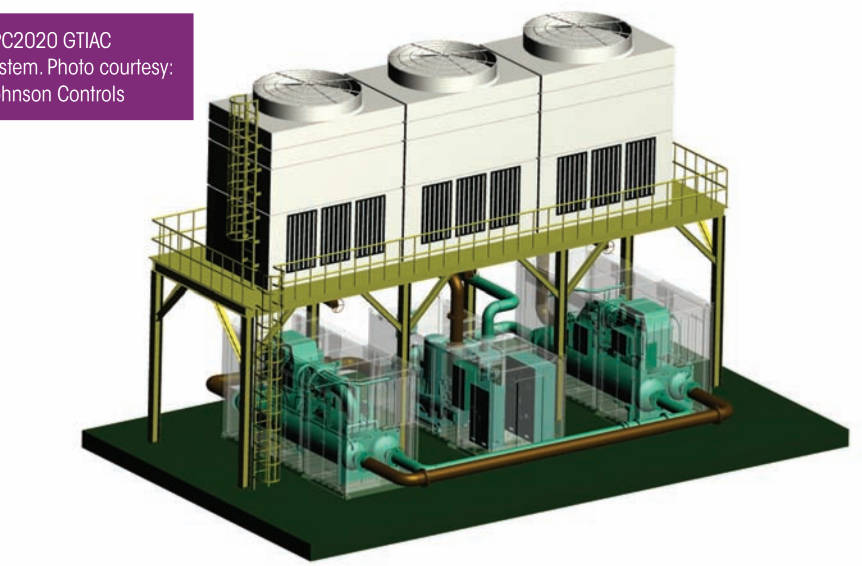
Parallel Chiller Configuration 1



the chillers, reducing GTIAC system parasitic load significantly. The direct impact of this is smaller chiller motors and smaller cooling towers or radiators for the cooling water circuit. Also, a higher chilled water delta T will reduce the size of the chilled water pumps. As for a given cooling capacity, the larger the chilled water delta T, the lower the flow required through the cooling coils. The chilled water piping, fittings, valves and insulation, as well as their associated installation works, decrease as the piping diameters are reduced as a result of the lower chilled water flow rate.

With this lower flow, higher delta T chilled water delivery means that the cooling coil LMTD is reduced and a larger heat transfer surface is required to maintain the gas turbine inlet air set point. Increasing the heat transfer area of the coils does lead to a slightly higher coil first cost, relative to the high LMTD design, however, the cost reduction on the system balance of plant will more than maintain the overall GTIAC system first cost. The significantly lower parasitic load will however provide sustained economic benefits.

The pressure drop across the cooling coils with a larger heat transfer area can be maintained within acceptable limits and not impact gas turbine performance, provided proper tube geometry and fin spacing is selected.



YPC2020 GTIAC system. Photo courtesy: Johnson Controls

The fin spacing on the coils is also an important consideration in the management of condensation formation which is unavoidable in humid ambient conditions and can cause damage to the gas turbine if carried over by the airstream into the compressor. To avoid this, careful design of condensation collection manifolds and drain channels in the coil sections is essential. The installation of a 'drift' eliminator downstream of the coils also traps any water droplets that are carried off the coils by the airstream before they travel to the gas turbine intake bell mouth.

THE CHILLED WATER SYSTEM

We now turn to the design of the chiller plant system. Once the cooling set point and GTIAC system duty has been established, the chiller units themselves have to be configured. This requires sizing the unit's compressor, evaporator and condenser for the application, using proprietary software modelling tools, relative to the available heat rejection cooling source water temperature. This heat rejection source can be supplied from the main plant cooling water system, a cooling tower, radiator or air cooled condenser.

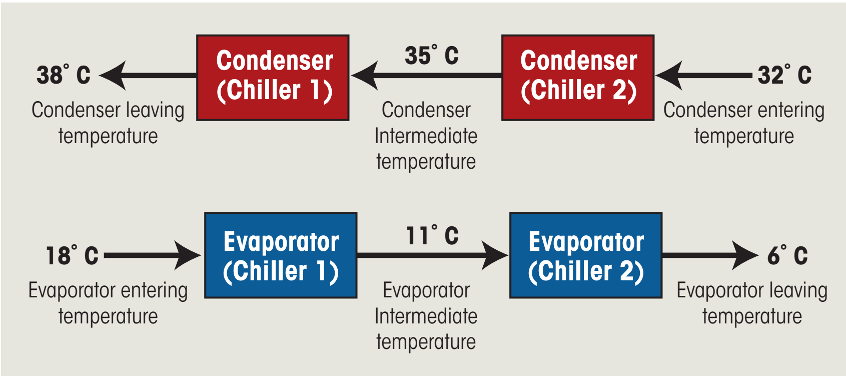
Selecting the correct chiller unit configuration for the GTIAC system is fundamental in optimizing the system performance from a parasitic load perspective. However, the configuration of chillers within the GTIAC system can also have a great bearing on the system parasitic power consumption. The vast majority of GTIAC systems involve more than one chiller unit. For GTIAC systems that use multiple chillers, the interconnection piping arrangement impacts the system efficiency. Connection of chillers in parallel arrangement, or in series counterflow arrangement, delivers different system efficiency; the series counterflow configuration can reduce the compressor work needed on each chiller, improving the overall chiller system efficiency by as much as 8%.

For a series counterflow chiller configuration, the chillers are arranged in pairs with chilled water circuits connected in series with the condenser water in series counterflow. All of the chilled water flow through both evaporators. All of the condenser water flows through both condensers.

The water ranges are split which allows a lower temperature difference or "lift" on each chiller than multiple units in parallel. The Chiller "lift" is the difference between the pressure at the saturated evaporative and condenser temperatures which can be easily seen in the chiller water temperature. Minimizing the approach between the evaporation temperature and chilled water leaving temperature as well as the condensing temperature and the cooling water leaving water temperature is key to minimizing this "lift". Chillers employing enhanced heat transfer tubing are best suited to reducing these approach temperature.

In the above example, the total lift required by the parallel chiller configuration is 32˚C (difference between leaving condenser water temperature at 32˚C and leaving chilled water temperature at 6˚C); whereas, in the series counterflow the condensers are piped in series counterflow to the chilled water piping. This arrangement enhances the chiller performance by

Series Counterflow Chiller Configuration 2



"cascading" the chillers. The above figure shows the lift requirements for series chillers, in this arrangement both chillers 1 and 2 have smaller lift than those of the parallel chiller arrangement: chiller 1 has a lift of 27°C (difference between condenser water temperature at 38°C and intermediate chilled water temperature 11°C); chiller 2 has a lift of 29°C (difference between intermediate condenser water temperature at 35°C and leaving chilled water temperature at 6°C).

Hence, we determined that series counterflow application can provide significant energy savings for GTIAC systems which have chilled and condenser water temperature ranges greater than a typical chilled water application.

To optimize the selection of appropriate chiller for a series counterflow configuration, the machine at higher temperature level will typically provide slightly more than half the capacity. The compressor motors and gear codes on the two chillers are often matched, such that the high temperature machine can operate at the low temperature conditions when one unit is cycled off at part load cooling capacity. Apart from this, the chillers are also generally selected as single pass chillers so the overall pressure drop is the same as a typical two pass chiller.

MODULARIZED GTIAC SYSTEMS

Site space constraints are not uncommon on new build power plants, but, green field development does afford the opportunity to plan and integrate the components of the GTIAC system into the power plant configuration. This can include the opportunity to integrate the GTIAC heat rejection requirements into the main plant cooling water system, construct a plant room to house the GTIAC chillers, pumps and auxiliaries as well as locate the electrical switchgear in main plant Electrical Distribution Centre. Climatically sensitive control equipment can also be housed in the plant control room.

On brown field sites, retrofitting a GTIAC system into an existing power plant operation presents significant challenges such as space constraints which results in little opportunities for integration of the GTIAC system components within the existing plant architecture. The solution for such a situation would be to consider a modularized GTIAC systems. The modularized system is delivered to site in self-contained skid mounted units pre-piped, cabled and assembled to be connected up at site. These modules generally include separate skids for the chillers, the circulating water pumps and a dry module housing the electrical switchgear and GTIAC system controller. These modules are placed on pre-prepared foundations, connected to the heat rejection source and chilled water delivery piping, ready for final site commissioning. As the modules are assembled in the controlled environment of the build shop, a large degree of commissioning and testing can be completed before they are delivered to site, reducing the lead time and resources required in erection and start up. Although the modularized system approach is well-suited to brown field applications, it is equally applicable and provides the same quality and lead time benefits when applied to new build power plant developments.

GTIAC systems need to be first cost competitive, highly efficient and have minimal site footprint in order to meet the needs of the market and gain greater acceptance. In recognition of this, JCI developed the YORK YCP GTIAC system which is designed as a three module system, with modules being standard 20′ shipping container sized for most economic transportation, two chiller modules and a single auxiliaries module housing the pumps, electrics and controls. The 8,000kW$_{ththt}$ rated YCP system is centered on a new chiller design which has been specifically developed for GTIAC application.

In conclusion, the GTIAC system needs to be considered holistically at the design stage to obtain the best life time performance from the system. Ensuring that the chilled water system and cooling coils are correctly matched, the chilled water delivery and delta T temperatures are as high as possible and the chiller units are arranged in series counterflow, will provide the user with optimal lifetime GTIAC system performance. pe