Boosting Power Output — Cool!
Options for Inlet Cooling in Gas Turbine Installations

By John Langaker, PE, and Zachary Loehr

Many power generating gas turbine installations in the U.S. and worldwide have an untapped resource for extending power output: inlet air cooling. These turbines can run at higher efficiency and output using cooled inlet air compared to hot ambient air. Cooler (or denser) air increases mass flow per unit volume. In single-speed, constant-volume machines such as most large gas turbines, that translates to higher output.

As demand grows, conditioning the turbine inlet air is an excellent way to expand a fleet’s ratings in the critical summer demand season since this method does not necessarily trigger a new source of air-polluting emissions. A gas turbine owner needs to recognize cooling gains available, the options to get them and ultimately adopt a solution tailored to the owner’s needs, independent of manufacturer preferences or biases.

Gains

Anyone who owns or operates gas turbines knows that performance improves as the units consume cooler air. Trends utilizing evaporative coolers are summarized in Figures 1 and 2. In general, single-speed frame machines that do not change the running-flow path geometry all share roughly the same margin for gain in comparing hot ambient operation to cooler. Aero-derivative gas turbines, which operate using multiple-speed, multi-shaft designs, offer a slightly different gain profile with cooler inlet air compared to hot.

As demand grows, conditioning the turbine inlet air is an excellent way to expand a fleet’s ratings in the critical summer demand season.

All gas turbines will approach a point of concern, however, as ice forms in the inlet, which threatens first-stage compressor damage. Therefore, an ideal air inlet temperature will avoid temperatures too close to this threshold yet still offer significant payback for the cooling system investment.

Existing Cooling Systems

Partial gains with existing systems may already be the optimum solution, particularly if an economic cost-benefit analysis was done initially.
Many gas turbines are purchased and installed with economical solutions directly from the turbine manufacturer. These systems, while well-proven, tend to sacrifice the maximum potential of the turbine in presenting a standardized system at minimal cost. An unbiased review of existing system design on a gas turbine should review the benefits of the system as-is compared to other viable cooling system options and using the operator/owner's own values for cost and returns on the investment. Among other factors, consider whether the owners are happy with what they have (i.e., operability).

**New Turbine Installation Opportunities**

When a utility is in the market to purchase installed capacity by means of one or more gas turbine generator sets, it is wise to understand the payback opportunity of various systems in relation to initial cost, complexity and value of the additional capacity and efficiency. It is also important to understand the advantages and disadvantages of the different cooling systems. Should a risk factor be used in comparing the options, so availability is considered? Absolutely.

**Cooling Air Methods: Advantages and Challenges**

In addition to packaged systems, methods of cooling gas turbine intake air include evaporative cooling, fogging, online chilled-water cooling and thermal energy storage. The methods vary in cost and complexity — and each has advantages and challenges. Summarized below from the simplest and most familiar to the most complex, these cooling methods increase gas turbine efficiency.

**Evaporative Cooling**

Also known as swamp coolers, because they achieve swamp-like conditions of near-full humidity in the air passing through, evaporative coolers are the most common cooling system that gas turbine manufacturers feature on new units. The air entering the turbine is pulled through media saturated with good-quality water (potable or service-grade). Heat from the air is transferred to the wetted surfaces of the media and converts the liquid water to vapor phase. This removes heat effectively equal to the latent heat of vaporization of the water at the conditions present.

**Advantages:** A simple system that operates with easily-obtained water quality.

**Challenges:** Water’s latent heat of vaporization is the dominant method to transfer heat from the passing air. Thus, the wet-bulb temperature is the absolute limit to which the air can be cooled. Nominal-effectiveness performance losses bump up the final air temperature slightly higher. Typical effectiveness is approximately 85%.
Fogging
Whereas traditional evaporative cooling has intrinsic limitations in effective heat transfer, fogging promises to fully absorb water injected into the air as a fine mist or fog. There is no blow-down or discharge from a fogging system; all is ingested into the gas turbine.

Advantages: Maintained correctly, both water consumption and the cooling effects (compared to the ambient wet-bulb temperature of the air as it enters the filter house) can be optimized.

Challenges: Water quality must be demineralized grade and fog nozzles must be maintained to ensure droplets are properly atomized as they pass into the inlet air structure, or costly damage to the gas turbine can result.

Online Chilled Water Cooling
To cool the inlet air to less than the ambient wet-bulb temperature, a chilling system can be installed to circulate coolant in a closed loop that includes inlet air coils mounted inside or in front of the filter house to extract heat and chillers to reject the same heat. Depending on fluid type used, the work required to chill the coolant is offset in power output gains to varying degrees.

Advantages: Gas turbine performance can be truly optimized by conditioning the inlet air regardless of the ambient wet-bulb temperature.

Challenges: The chilled-liquid loop and chiller systems are more complex than evaporative cooling or fogging and present inherent trade-offs between efficiency and maintenance costs. Mechanical chillers also require higher auxiliary loads compared to other cooling options.

Thermal Energy Storage
As the use of online chilling has gained popularity for gas turbine enhancement in hotter ambient conditions, thermal storage has emerged to further reduce the cost of the power boost of cooler inlet air.

The tonnage (size) of the chillers can be reduced when incorporated into an insulated tank system that is exhausted and replenished in cycles suited to the optimal periods of cooled gas-turbine operation. Lower tonnage equates to lower auxiliary electrical load that otherwise deducts from plant net output. Timing of the auxiliary load can also be managed to mitigate the cost, since electricity billing rates may vary according to the time of day.

In addition to allowing timing of chiller loads, thermal storage may present the opportunity to draw power for smaller chillers from renewable energy sources, such as wind at night. The stored thermal energy can then be used to chill gas turbines or supply chilled-water systems during daytime peak-demand periods.

Advantages: This is an approach that may quickly pay for itself and further enhance the power-output net gains of online chilling with its concurrent auxiliary-plant electrical loads.

Challenges: Thermal energy storage presents the highest degree of complexity for plant operation compared to its counterpart technologies and is most sensitive to changing rates of return on the investment made.

To capitalize on available gains, conditioning inlet air should be studied early in any utility’s plan to expand a fleet’s ratings. Owners should recognize what cooling gains are available and the options to achieve them.

Packaged Systems
Whether you are building a home for yourself or constructing a greenfield power plant, packaged solutions are alluring for several reasons.
To begin with, a packaged system will marry equipment and logic that is (hopefully) time-tested in other installations, which imparts a degree of reliability and ease of operation.

It should be recognized that a packaged gas-turbine inlet air cooling system has taken measures to unify its mode of construction and operation among many different customers’ needs. For example, is the pressure drop across the cooling media or coil bundle optimized for the loss in power output and gain in heat rate?

The answer depends on owners’ specific costs of power. Among other factors, the individual results of a packaged system depend on how closely an owner’s economic profile matches the packager’s typical customer.

**Conclusion**

Owners of gas turbines will enjoy higher efficiency output with cooled inlet air when the hotter seasons arrive. However, there are many installations in the U.S. and the world where gas turbine inlet-air cooling is an underutilized or altogether untapped resource for extending power output.

To capitalize on available gains, conditioning turbine inlet air should be studied early in any utility’s plan to expand a fleet’s ratings. One should recognize what cooling gains are available and the options to achieve them.

The solution should then be tailored to the owner’s needs, independent of manufacturer preferences or biases.