Inlet Air Cooling – Design Point & Economics

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Combustion Turbine Inlet Air Cooling (CTIAC) systems have been installed on thousands of combustion turbines to recover the lost power due to high ambient temperatures. Within the technology of CTIAC, there are many methods employed to cool the air entering the combustion turbine (CT) to recover this lost power: ***fog/evap cooling***, ***chilling*** and ***wet compression technology***.

Companies market CTIAC products based on their cost and performance at a particular design point, expressed as $/kW. Buying power augmentation on the basis of a particular design points $/kW is misleading, since design conditions may occur only a fraction of the operational time of the system. Power plant revenues are typically based on the available capacity and the hours they generate and sell power. Therefore, a better approach is to calculate the energy increment (kW-hours) available during the day and/or year and the increased capacity of the plant. This could be further sub-divided into on-peak and off-peak increments. An evaluation on this basis is a more realistic indicator of the economic feasibility of a particular CTIAC system.

Technology Brief

Although all three power augmentation technologies enhance the turbine capacity at high ambient conditions, some are heavily dependent on the ambient conditions as to how well they perform. For instance, at high humid conditions, a fog/evap cooling system will offer little or no benefit. At those same high humid conditions, a chilling system's benefit is significantly reduced, due to the added moisture that must be condensed under such scenarios. Wet compression is a power augmentation technology whose performance is not significantly impacted by ambient conditions.

> ***Fog/Evap Cooling***: Inlet air is cooled by either passing the air through a wetted media, or spraying fine water droplets into the inlet air stream. As the water evaporates, it adiabatically cools the air due to the latent heat of vaporization required. The ambient wet bulb temperature limits this type of cooling and these systems are not typically run if the difference between dry bulb and wet bulb temperature is less than 4ºF.
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> ***Chilling***: Inlet air is cooled by a chilled fluid circulating through cooling coils placed inside the ductwork. Typically, mechanical chillers are utilized to provide cooling to the heat transfer fluid circulating through the coils. Absorption chillers may also be used but do not have the same cyclic duty or part load capabilities. Thermal energy storage systems are sometimes utilized to optimize output during peak hours only, by shifting a large portion of the auxiliary load requirements to off-peak periods. These systems cool the air to below wet bulb temperature to a pre-selected set point, typically in the 45-55ºF range.
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> ***Wet Compression***: (also referred to as "high-fogging" and "overspray") Wet compression is often classified as an inlet air cooling technology, since it recovers lost power due to high ambient conditions, but it works equally well during moderate ambient conditions. Wet compression is a patented technology that is installed in the CT inlet, but acts as a compressor inter-cooler. These systems inject finely atomized water into the compressor of the CT. As the air is heated due to the work of compression, the water evaporates, cooling the compressor air between stages. This results in a more efficient compressor, thus

making the entire CT cycle more efficient. Wet compression can be installed in addition to fog/evap cooling or chilling systems to further increase the power output and efficiency of a power plant.

The typical locations of these systems are illustrated in *Figure 1*. Both evap media and chilling systems permanently increase the airside pressure drop of the inlet systems, even when these systems are not operational. Fogging systems and wet compression systems have no measurable increase in pressure drop.

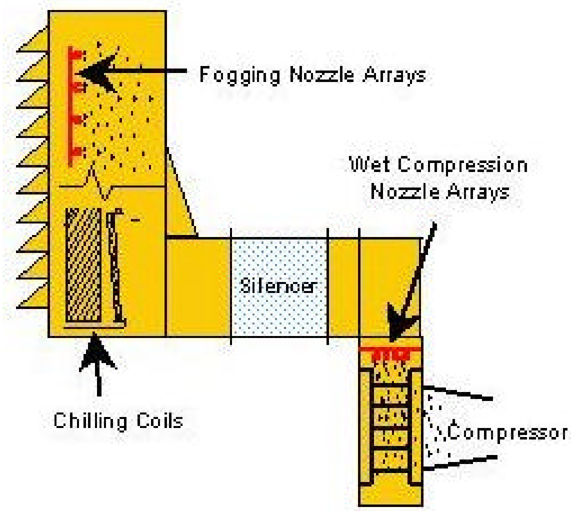

Figure 1: Technology Locations in Ductwork

System Design Point

The design of a CTIAC system is based on a defined design ambient condition. This is typically the worst-case ambient condition that may occur in a given year. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has developed standard tables of design points for various locations throughout the United States and the World. These design points are based on historical weather data and are grouped into bands where the average data are reported to exceed the reference conditions 0.4%, 1% or 2% of the time in any given year. As an example, a location with a 0.4% design temperature of 90°F will exceed this temperature for an average of 0.4%, or 35 hours per year. A design on this basis requires that the capital cost is based on a small percentage of the actual operating hours of the plant.

If a system is optimally designed for conditions that occur only 0.4% (35 hours) of the year, what are the system economics for the remaining 99.6% (8,725 hours)?

To illustrate this concept and answer this question, we will evaluate three design days; a hot day, a cool day and a humid day. The "value" of the equipments capital cost and the return on investment will be illustrated for each system, as a result of the added power generated by each. The ambient conditions for each design day are listed in *Table 1*.

Table 1: Ambient Conditions

	T dry bulb (° F)	T wet bulb (° F)	R.H. (%)
Hot Day	90 (32 °C)	60 (15 °C)	15%
Cool Day	67 (19 °C)	50 (10 °C)	27%
Humid Day	72 (22 °C)	64 (18 °C)	65%

Power generators think of capital plant costs in terms of dollars per kW of power generation ($/kW). To apply this same philosophy to CTIAC power augmentation systems is misleading, as most CTIAC systems are highly ambient dependent and have significant swings in instantaneous $/kW. A lower $/kW may not have better performance or yield a better rate of return for the capital outlay. Therefore, the average $/kW for any given 24 hour day is a much better indicator of the true cost for a system, as illustrated by the following example.

The “design point” of any CTIAC system may occur for only a brief period of time each year, and in actuality, may never occur. Considering this, hourly costs ($/kW) are averaged over the entire day that a system is used. In doing this, for a hot day, the wet compression average cost is $63/kW, fog/evap cooling is $98/kW and chilling is $210/kW, as depicted in the first set of bar charts in Figure 2. The significant difference between these technologies is due to the varying spread between dry and wet bulb temperature throughout the day and the fact that fog/evap cooling and chilling systems performance are significantly dependent on ambient fluctuations.

The energy gains (MWh) for the same 24-hour hot day are depicted in Figure 3; 854 MWh for wet compression, 235 MWh for fog/evap cooling and 301 MWh for chilling. This represents the increase in “saleable” energy as a result of the various systems operating for a 24-hour period.

Similarly, figures 2 and 3 also illustrate the average cost and MWh gains for the cool day and humid day.

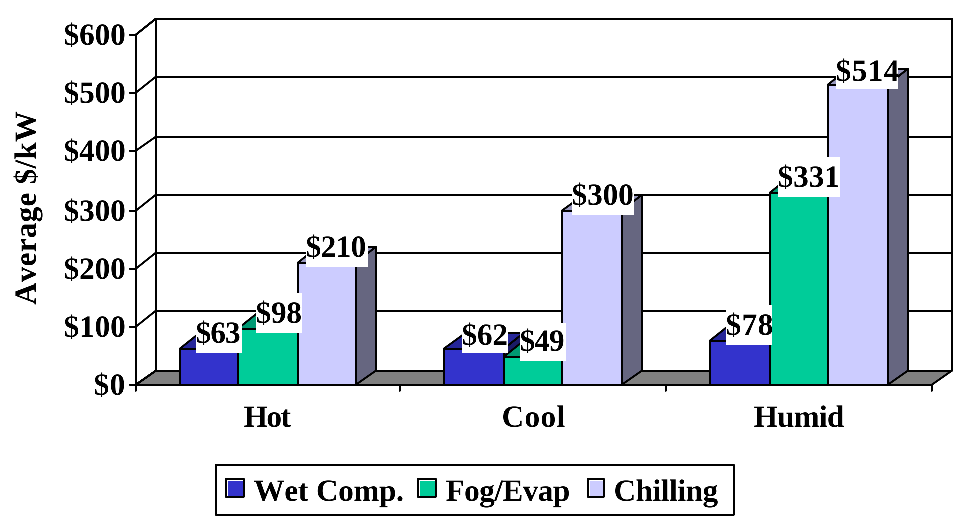

Figure 2: Cost per kW of Power Augmentation for 24-hour Period

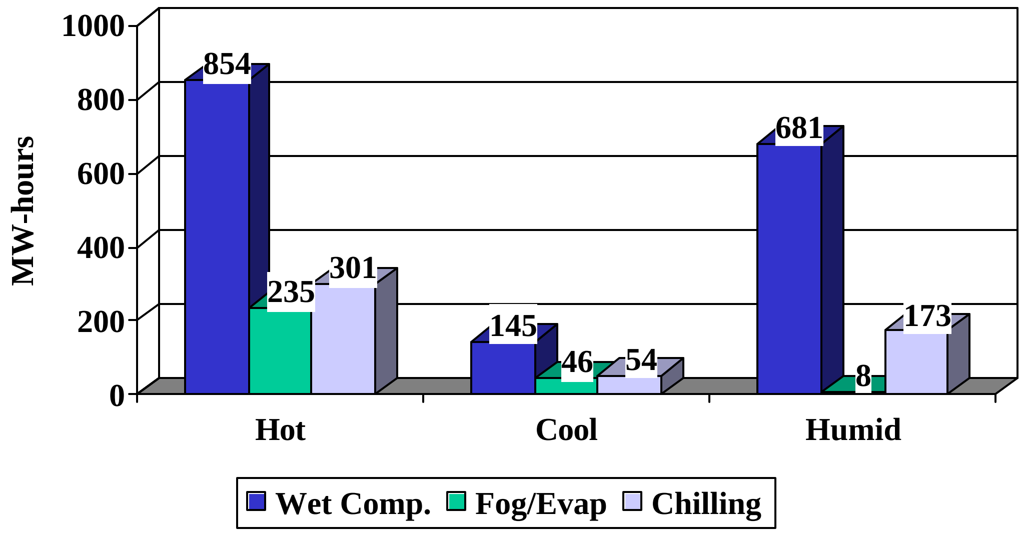

Figure 3: Increased Daily Energy from CTIAC Power Augmentation System

Return on Investment

Evaluating the return on investment for the various technologies requires an in-depth analysis of the costs and profitability for the particular power plant. For purposes of this study, reasonable assumptions are made for each technology that will represent the relative rate of return for each technology.

For purposes of this analysis, the following assumptions are made: 1) the number of days in a given year that the systems are run for hot, cool and humid days are 60, 30 and 60 days, respectively; 2) the profit from sales of energy for the power generator is $ 0.03 per kWh. These assumptions can be varied, but for comparison purposes should be representative of the relative difference in each CTIAC power augmentation technology. Table 2 illustrates the energy gains and the return on investment for the three technologies.

Table 2

	Increased Power (kWh)		
Days	**Wet Compression**	**Fog/Evap**	**Chilling**
(60) Hot	51,240,000	14,100,000	18,060,000
(30) Cool	4,350,000	1,380,000	1,620,000
(60 Humid	40,860,000	480,000	10,380,000
Total Increase (kWh)	**96,450,000**	**15,960,000**	**30,060,000**

Increased Profit	$2,893,500	$478,800	$901,800
System Cost [1]	$2,200,000	$530,000	$3,200,000
Annual R.O.I	**131%**	**90%**	**28%**

1 – Cost is for two 120 MW class combustion turbines in combined cycle.

Fog/evap cooling systems are relatively inexpensive and realize significant power gains during the heat of the day. These systems appear very inexpensive at the hot day design point, but are highly ambient dependent and offer little benefit in the mornings, evenings or on humid days.

Chilling systems are a significant capital expense due to the equipment and manpower required for the technology. The benefit is ambient dependent, where the CT power gains are determined by the difference in the ambient dry bulb temperature and the inlet chilling system design capability. System auxiliary loads and initial sizing are based on the system cooling the inlet air to below the wet bulb temperature.

Wet compression systems offer more consistent power gains throughout the day. These systems are not as ambient dependent, as they actually intercool the compressor, increasing its efficiency. Actual experience from a customer with an installed wet compression system that ran for over 6000 hours in one year had an average gain of 15 MW per hour, that totals an increase of 90,000 MWh's. Assuming a conservative profit of 2 cents per kWh, the actual return on investment for this system is 150%!

Summary

Careful consideration should be given in picking a "design point" for the CTIAC systems, as this will greatly affect system cost, performance and impact economic feasibility. Daily variances in ambient conditions greatly influence a system's return on investment, particularly those that are highly ambient dependent - fog/evap cooling and chilling. Qualified and experienced personnel should perform careful analysis in order to accurately evaluate which technology, or combination thereof, is best suited for a particular installation.