Energy Conversion and Management 75 (2013) 214–223

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Impact of the use of a hybrid turbine inlet air cooling system in arid climates

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ARTICLE INFO

Article history:
Received 7 February 2013
Accepted 1 June 2013

Keywords:
Gas turbine inlet air
Energy saving
Mechanical chiller
Evaporative cooler

ABSTRACT

Cooling the air entering the compressor section of gas turbine power plants is a proven method of increasing their power output, especially during peak summer demand, and it is increasingly being used in power plants worldwide. Two turbine inlet air cooling (TIAC) systems are widely used: evaporative cooling and mechanical chilling. In this work, the prospects of using a hybrid turbine inlet air cooling (TIAC) system are investigated. The hybrid system consists of mechanical chilling followed by evaporative cooling. Such a system is capable of achieving a significant reduction in inlet air temperature that satisfies the desired power output levels, while consuming less power than the conventional mechanical chilling. Furthermore, less water than conventional evaporative cooling can be used, thus combining the benefits of both approaches is proposed in this study. Two hybrid system configurations are studied. In the first configuration, the first stage of the system uses water-cooled chillers that are coupled with dry coolers such that the condenser cooling water remains in a closed loop. In the second configuration, the first stage of the system uses water-cooled chillers but with conventional cooling towers. An assessment of the performance and economics of those two configurations is made by comparing them to a conventional mechanical chilling and using realistic data. It was found that the TIAC systems are capable of boosting the power output of the gas turbine by 10% or more (of the power output of the ISO conditions). The cost operation analysis shows clearly that the hybrid TIAC method with wet cooling has the advantage over the other methods and It would be profitable to install it in the new gas turbine power plants.

1. Introduction

It is well known that the power output of combustion gas turbines decreases significantly as the ambient temperature increases. Fig. 1 demonstrates this phenomenon, which is attributed to the fact that gas turbines are considered constant volumetric flow rate machines. As the temperature of air entering the compressor section of the turbine increases, it becomes less dense and, thus, the mass flow rate of air decreases, causing the power output to decrease as well. The figure indicates also that a 1 °C increase in temperature leads to a decrease in power output of approximately 0.64%, explaining the significant decrease in gas turbine power output during hot summer months when the demand is at its highest. For this reason, it is highly desirable to keep the turbine inlet air temperature as low as possible by cooling the incoming ambient air.

One proven method of increasing turbine power output is to cool the air entering the compressor section during periods when the ambient temperature is high and the demand for electric power is high. By doing so, the density of air increases, which in turn increases the mass flow rate of air and power output of the turbine. To demonstrate the impact of turbine inlet air cooling (TIAC), a commercial gas turbine which operates on natural gas is considered. According to [1], the power output of such a turbine at an ambient temperature of 45 °C is approximately 69 MW. If the incoming air is cooled to 15 °C, the turbine power output will increase to about 84.4 MW. In other words, by cooling the incoming air, the power output is increased by more than 20%.

Due to the favorable prospects of TIAC, this concept is increasingly being implemented in power plants worldwide. While there are a variety of ways to cool the incoming air, the most widely used method is the evaporative cooling. This method is based on the simple idea that the temperature of air can drop significantly if it is humidified. However, the extent to which air can be cooled using this method depends primarily on the relative humidity of air. Fig. 2 demonstrates this limitation. Point 1 shows the condition of air whose dry bulb temperature is high while its relative humidity is low. This condition is representative of hot desert climates. Assuming that evaporative cooling is performed adiabatically, the temperature of the air leaving the evaporative cooler will approach the wet bulb temperature of ambient air which, in this case, is considerably low (20 °C). On the other hand, Point 2 shows the

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0196-8904/$ - see front matter
http://dx.doi.org/10.1016/j.enconman.2013.06.005

Nomenclature

ISO	International Organization for Standardization
$\dot{m}$	flow rate (kg/s)
P	pressure (kPa)
RH	relative humidity
TIAC	turbine inlet air cooling
T	temperature (°C)
w	humidity ratio (kg water vapor/kg dry air)

Subscripts

a	air
chw	chilled water
cw	condenser water
ecw	entering condenser water
echw	entering chilled water
evap	evaporative cooler
f	after humidification
i	before humidification
lwt	leaving water temperature
wb	wet-bulb

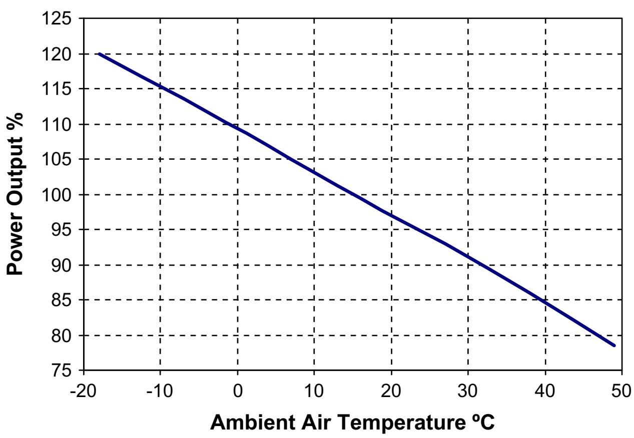

Fig. 1. Variation of power output with ambient air temperature for a commercial gas turbine (power output is normalized to the value at 15 °C) [1].

condition of air whose both dry bulb temperature and relative humidity are high. The air leaving the evaporative cooler will also approach the wet bulb temperature of ambient air but, in this case, this temperature is significantly higher (25 °C). This means that using evaporative cooling for TIAC will yield a larger increase in the power output in arid climates than in humid climates. Evaporative cooling systems also have the advantages of being simple, inexpensive, reliable, and requiring minimal power. One of the disadvantages of evaporative cooling systems is that they consume large amounts of water, making them less attractive in places where water resources are not readily available. Care should also be taken to prevent water droplets from being carried into the compressor section and damaging the compressor blades. However, the very fact that large amounts of water are added to the air stream contributes to power augmentation.

Another popular TIAC method is mechanical chilling. In this method, hot ambient air is passed over a cooling coil which is fed with chilled water (or brine) coming from a chiller. Fig. 3 demonstrates the air cooling process on the psychrometric chart. Close examination of the cooling process reveals that the main advantage of the mechanical chilling is that air can be cooled to temperatures well below the wet-bulb temperature. In fact, chiller systems can potentially dehumidify the incoming air stream, minimizing in the risk of damaging to the compressor blades. On the other hand, mechanical chilling is characterized with high initial

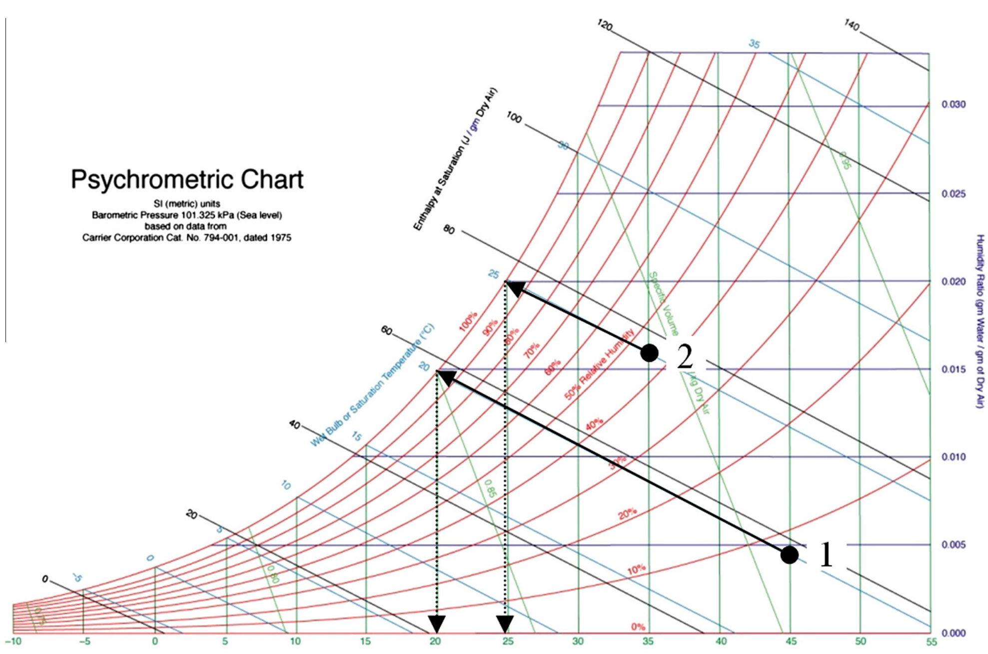

Fig. 2. Effect of relative humidity on wet bulb temperature.