COOL YOUR JETS!

Thermal Energy Storage Technologies for Turbine Inlet Cooling

This column continues the ongoing series regarding turbine inlet cooling (TIC). The current column discusses various Thermal Energy Storage (TES) technologies applied to TIC. While all TIC technologies have their advantages and limitations, the selection of an optimum TIC technology (and the specific TES technology) for a specific power plant depends on a number of factors, including the plant's geographical location, CT characteristics, plant operating mode, time-of-day market value of electric energy, fuel cost, desired level of performance enhancement, and investment hurdle rates.

The TES Concept

A TES-TIC system utilizes all the component elements of a non-TES chiller-based TIC system. However, TES allows for the time-based decoupling of all or some of the chiller plant operation from the usage of cooling at the turbine's inlet air cooling coils. This is accomplished by operating chillers during off-peak times (when the value of power is relatively low) to freeze ice or to chill a storage tank of water or fluid. Subsequently, during on-peak periods (when the value of power is high) the storage is utilized (melting the ice or reheating the stored water or fluid) to meet peak cooling loads at the turbine inlet air cooling coils.

A dual-benefit is achieved by utilizing TES in this manner:

1. Parasitic loads associated with chiller operation are eliminated or largely reduced during on-peak periods when power is at its highest value. (The chillers operate entirely or primarily during off-peak periods, when the cost or value of power is lower.)
2. The chiller plant can be reduced in capacity and capital cost, often more than compensating for the capital cost of the TES installation.

Advantages & Limitations of TES

All TIC technologies have advantages and limitations. It is always important to understand and evaluate technology options for each application.

The use of TES for TIC maintains the basic attributes and benefits of a non-TES chiller system used for TIC. TES allows cooling of the turbine inlet air to temperatures lower than those possible with evaporative cooling technologies and thus, achieves much higher power capacity enhancement. The TES-chiller system allows cooling of inlet air to any desired temperature within the limitations of the selected chiller(s). The TES-chiller system does not require elaborate water treatment and consumes very little water compared to evaporative cooling.

TES systems are most often mated to electric motor-driven chillers; however, TES systems are also frequently applied with steam turbine-driven, engine-driven, and absorption chiller systems, as well as with hybrid systems using a mix of chiller technologies.

Supplementing a chiller system with TES helps to address the non-TES chiller system's primary drawback, namely a relatively high capital cost compared to evaporative cooling systems.

The Key Advantages of TES for TIC

1. Reduced parasitic power losses, on-peak
2. Reduced capacity and cost of chiller plant
3. Lower capital cost per MW of power enhancement, on-peak
4. Maximized net power enhancement, on-peak

The Key Limitations of TES for TIC

1. Space for the TES tank
2. Limited hours per day of maximum power enhancement

Comparing TES Options for TIC

Various TES technology options are available and already in use in TIC applications. There are two families of TES technologies:

1. Latent heat TES, notably ice (i.e., "static" ice TES such as "ice-on-coil," or "encapsulated ice" and "dynamic" ice TES such as "ice harvesters")
2. Sensible heat TES including chilled water (CHW) and low temperature fluid (LTF) storage.

Each technology has unique characteristics and therefore inherent advantages and limitations. As a generalization, the distinctions are presented in Table 1.

Table 1: Generalized Inherent Characteristics of TES Technologies for TIC

	Latent Heat (Ice) TES		Sensible Heat TES	
	Static Ice	Dynamic Ice	Chilled Water	LT Fluid
Volume	good	fair	poor	fair
Footprint	good	good	fair	good
Modularity	excellent	good	poor	good
Economy-of-Scale	poor	fair	excellent	good
Energy Efficiency	fair	fair	excellent	good
Low Temp Capability	good	good	fair	excellent
Ease of Retrofit to Chillers	fair	poor	excellent	good
Rapid Discharge Capability	fair	excellent	good	good
Simplicity and Reliability	fair-good	fair	excellent	good
Site Remotely from Chillers	poor	poor	excellent	excellent
Dual-Use as Fire Protection	poor	poor	excellent	poor

As each TES technology has characteristics that range from excellent to poor, a thorough knowledge of those differences (and of the priorities of a particular application) is critical to achieving an optimum match for any specific situation. Beyond the choice of technology, there are many other variables to be considered in applying TES. These variables include such items as: full-shift versus partial-shift systems; daily versus weekly design cycles; operating supply and return temperatures; chiller and chiller driver types; redundant chiller capacity (if any); and siting of the TES equipment.

Specific Users of TES-TIC

To date, there has been more than 15 years of experience with TES-TIC installations. Such applications span a wide range of application types:

- ▲ TIC applied to new CTs, as well as retrofits to existing CTs;
- ▲ Applications for Simple-Cycle and Combined-Cycle CT plants;
- ▲ CT plant capacities ranging from 1 MW to 750 MW;
- ▲ Installations in North America, Europe, and Asia, including a wide range of climates, both hot-arid and hot-humid environments, as well as locales with year-round hot weather and those with only brief seasonal hot weather; and
- ▲ Various TES technology types, including Ice TES, Stratified Chilled Water (CHW) TES, and Stratified Low Temperature Fluid (LTF) TES.

The types of power plants using TES-TIC systems are mostly stand-alone power generation (utilities and IPPs). However, TES-TIC is also fairly common at District Energy systems (both at urban thermal utility systems and at university campus energy systems) where central cooling plants and onsite power generation are employed.

Power plants across the U.S. and around the globe are employing various TES-TIC technologies, with the earliest documented system in-service in the late 1980s. Detailed data from some of these installations is available within the Experience Database section of the Turbine Inlet Cooling Association website, www.turbineinletcooling.org. Table 2 provides a summary analysis of the recent TES-TIC installations from that database, including data ranges and data averages for various parameters of the plants.

Case Studies of TES-TIC Systems

Details for a representative recent examples are provided in the following Case Studies.

Case Study #1

District Energy (Combined Cooling, Heat & Power), Serving a Major Resort Complex

Plant & TES-TIC Data

- ▲ Central Florida (hot-humid climate)
- ▲ Existing 32 MW (ISO) CT in Combined-Cycle plant
- ▲ 1 x GE LM5000 + 1 x Steam Turbine Generator
- ▲ Added TIC, from 95°F to 50°F air temp
- ▲ 2,000 ton TIC load, 10 hours per day
- ▲ Used existing 14,425 ton electric-driven mechanical and absorption chiller plant
- ▲ Growing District Cooling loads required 3,315 tons in new chiller plant peaking capacity
- ▲ No new chillers were added
- ▲ Added CT inlet cooling coils (replacing existing evaporative cooling TIC system), plus
- ▲ 57,000 ton-hours of stratified chilled water TES (full load shift for TIC, partial shift for District Cooling)

TES-TIC Results

- ▲ TES-TIC in-service in 1998
- ▲ 8 MW (31%) enhancement in hot weather power output
- ▲ 4 MW in Demand-Side Management of the District Cooling system
- ▲ 12 MW total net reduction in on-peak purchased power
- ▲ Low unit capital cost per MW of power enhancement
- ▲ Saved approx. 2,000 tons of installed new chiller plant capacity for TIC
- ▲ Saved about 3,315 tons of installed new chiller plant capacity for District Cooling
- ▲ Saved about 5,315 tons of total installed new chiller plant capacity (no new chillers were added)
- ▲ Created and captured several million dollars in Net Present Value

Case Study #2

Electric Utility

Plant & TES-TIC Data

- ▲ Middle East (hot-arid climate)
- ▲ Existing 750 MW (ISO) Simple-Cycle plant
- ▲ 10 x GE 7EA CTs
- ▲ Added TIC, from 122°F to 54.5°F air temp
- ▲ Approx. 30,000-ton TIC load, 6 hours per day
- ▲ Added approx. 11,000-ton electric-driven mechanical chiller plant
- ▲ Added 193,000 ton-hours of stratified chilled water TES (full load shift)

TES-TIC Results

- ▲ TES-TIC in-service in 2004
- ▲ 30% enhancement in hot weather power output
- ▲ Low unit capital cost per MW of power enhancement
- ▲ Use of TES saved approx. 20,000 tons of installed chiller plant capacity
- ▲ Use of TES reduced on-peak parasitic loads (increased net on-peak power) by approx. 20 MW
- ▲ Use of TES saved approx. $10 million in capital cost versus a non-TES TIC chiller system

Summary

No one technology is universally best for all TIC applications. TES-TIC systems are being increasingly applied, particularly where the value of electric power varies significantly as a function of time-of-day on hot weather days. Of all available TIC technologies, TES-TIC systems provide the maximum hot weather CT power enhancement during on-peak periods. TES-TIC also offers significant reductions in total capital cost and in unit capital cost per MW of on-peak power enhancement, compared to non-TES chiller systems for TIC. TES is an option that should be considered and explored whenever maximized on-peak hot weather performance is desirable.

John S. Andrepont is the founder and president of The Cool Solutions Company, Lisle, Ill., and has 30 years of experience in energy technologies, including various turbine inlet cooling projects and over 100 thermal energy storage installations. Cool Solutions provides consulting services related to TIC, TES, and District Cooling systems. He is the current chairman and director of the Turbine Inlet Cooling Association (TICA). You may contact John via editorial@magellanpubs.com

Table 2: Analysis of Database of Recent TIC-TES Installations

	Data Range	Data Averages
First year in service	1988 to 2004	
Location	N. Amer./Europe/MidEast/SE Asia	
Plant type	SC & CC	
Number of CTs	1 to 10	3.2
CT OEM	GE, SWPC, Turbomeca & others	
CT plant capacity (ISO)	1 MW to 750 MW	170 MW
TIC enhancement	16% to 42%	27%
Design ambient air temp	90° to 122°F	100°F
Design TIC air temp	40° to 55°F	46°F
TIC load	30 to 30,000 tons	6,800 tons
Chiller plant capacity	380 to 16,800 tons	4,900 tons
TES discharge period	4 to 13 hours/day	6.5 hours/day
TES type	ice, chilled water, low temp fluid	
1988-1995	predominantly dynamic ice	
1996-2004	predominantly chilled water	
TES design cycle	daily & weekly	
1988-1995	predominantly weekly	
1996-2004	predominantly daily	
TES capacity	3,500 to 193,000 ton-hrs	70,000 ton-hrs