Turbine Inlet Cooling for Increasing Capacity and Reducing Emissions During Hot Weather

Dharam V. Punwani
President, Avalon Consulting, Inc.

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Turbine Inlet Cooling Association Webinar
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Presentation Outline

• Background: What is the problem that needs a solution?
• What is Turbine Inlet Cooling (TIC)?
• TIC Technologies
• Economic Benefits of TIC
• Environmental Benefits of TIC
• Factors Affecting the Performance of TIC Technologies
• Factors Affecting the Economics and Selection of TIC Technology
• Summary of the Presentation
Price of electric energy for the ratepayers goes up during the peak demand period: as much as 7 times that during the off-peak period.
Emissions (lbs/kWh) also Increase During On-Peak Period

Y-Axis Unit: CO₂ Emissions, lbs/kWh (California)
Source: Scot Duncan Presentation at ASHRAE June 2007
Problem:
Some of the Characteristics of Combustion Turbines
Some of the Unfortunate Characteristics of All Combustion Turbine Power Plants

During hot weather, just when power demand peaks,

1. Power output decreases
   - Up to 35% below rated capacity
   - Extent of the decrease depends on the CT design

2. Efficiency decreases leading to increased fuel consumption (higher heat rate) and increased emissions per kWh
   - Up to 15% below rated capacity
   - Extent of the decrease depends on the CT design
Effect of Hot Weather on CT Generation Capacity Depends on CT Design

Up to 19% capacity loss at peak demand for this CT
CT Power Plants Energy Efficiency Decreases (i.e. Heat Rate Increases) with Increase in Ambient Temperature

Fuel Use Increase (i.e. Energy Efficiency loss) at peak demand
Smaller Capacity Systems More Sensitive to Ambient Temperature

Capacity Loss of over 21% from ~10,750 kW to ~8,500 kW

Efficiency loss of over 8 % from HR of ~ 11,100 to ~12,000 Btu/kWh

Source: Solar Turbines
## Effect of Hot Weather on the U.S. Generation Capacity Reduction*

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Winter Capacity, MW</th>
<th>Summer Capacity, MW</th>
<th>Summer Capacity Loss, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum</td>
<td>60,878</td>
<td>56,781</td>
<td>4,097</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>432,309</td>
<td>401,272</td>
<td>31,037</td>
</tr>
</tbody>
</table>


* Most of it is due to the reduced capacity of combustion turbine
Major Components of a Combustion Turbine System

- Natural Gas
- Air Compressor
- Combustion Turbine
- Combustion Chamber
- Ambient Air
- Exhaust Gases to Atmosphere or for Heat Recovery for Cogeneration or Combined Cycle System
- Shaft Power
- Electric Generator

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Power output of a turbine is proportional to the mass flow rate of hot gases it receives from the combustion section.

Mass flow rate in the combustion section is proportional to the mass flow rate of the compressed air it receives from the compressor.

Mass flow rate capacity of a compressor is limited by its volumetric capacity for sucking in the inlet air.

Increase in ambient temperature reduces the air density that decreases the mass for the same volumetric flow rate through the compressor.

Reduced mass flow rate of compressed air reduces the mass flow rate of the hot combustor gases that leads to reduced power output of the combustion turbine.
Why CT Efficiency Decreases with Increase in Ambient Temperature?

- Compressor power requirement increases with increase in air temperature
- Compressor of a CT system consumes almost two-third of the turbine’s gross output
- Increased power required of the compressor reduces the net electric power available from the CT system
Solution:
Turbine Inlet Cooling
Cooling the inlet air before it enters the compressor or during its compression.
Turbine Inlet Cooling Technologies

- Direct Evaporation
  - Wetted Media, Fogging

- Indirect Evaporation

- Chilled Fluid using mechanical or absorption chillers:
  - Indirect or Direct Heat Exchange
Turbine Inlet Cooling Technologies

- Thermal Energy Storage (TES)
  - Chilled Fluid or Ice
- Wet Compression
- LNG Vaporization
- Hybrid
  - Some combination of two or more cooling technologies

Last year TICA completed a series of webinars on each technology.
Each TIC technology has its pros and cons.

No one technology is best for all applications.

Evaporative cooling systems can not cool the inlet air to lower than the wet-bulb temperature but require least capital cost and have least parasitic power need.

Chiller systems can be designed to cool the air to any desired temperature but require more capital cost and have high parasitic power need.
Turbine Inlet Cooling Technologies

- TES systems shift chiller parasitic load to off-peak period
- Wet compression improves compression efficiency and low parasitic load
- Hybrid systems minimize the parasitic load to achieve a desired inlet air temperature
- LNG vaporization only applicable where the power plant is located at/or need an LNG vaporization facility
Turbine Inlet Cooling Technologies are Simple and Proven

- Thousands of plants already benefiting from TIC
- TICA web site database of 100+ plants worldwide that are using TIC

www.turbineinletcooling.org/database.html
Turbine Inlet Cooling Technology Performance Calculator

Available on the TICA Website

http://www.turbineinletcooling.org/calculation_nonmem.php5

Member Version (Full Version)

Public Version (Partial Features)
Factors Affecting the Capacity Enhancement Potential of TIC

- TIC Technology
- CT Design Characteristics
- Weather Data (dry-bulb and coincident wet-bulb temperatures/humidity) for the Geographic Location of the CT
- Design Ambient Conditions
- Design Cooled Air Temperature (if allowed by the TIC technology)*

* Cooling achieved by evap technologies is limited by the humidity
Benefits of TIC

- Increased Capacity
- Increased Efficiency
- Reduced Emissions
- Reduced Unit Capital Cost ($/kW of capacity increase)
Examples of the Effect of TIC Technology and Humidity on Capacity Enhancement

Sources:
Wet Compression: Caldwell Energy, Inc.
All Others: D.V. Punwani Presentation, Electric Power 2008
TIC Overcomes the Effects of the CT Performance During Hot Weather

7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)
Las Vegas, NV (108°F and 8.6% RH): Solid
Anniston, AL (95°F and 42.5% RH): Shaded

Cooled Air Temperatures:
Las Vegas, NV
Wetted-Media: 70.3
Chiller: 50F
Anniston, AL
Wetted-Media: 77.9
Chiller: 50F

Net Capacity, MW

<table>
<thead>
<tr>
<th>TIC Technology</th>
<th>Rated</th>
<th>Ambient</th>
<th>Wetted-Media</th>
<th>Electric Chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>320</td>
<td>285</td>
<td>309</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td>291</td>
<td>301</td>
<td>322</td>
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Net Capacity Increase by TIC

7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)
Las Vegas, NV (108°F and 8.6% RH): Solid
Anniston, AL (95°F and 42.5% RH): Shaded

Cooled Air Temperatures:
Las Vegas, NV
Anniston, AL

Wetted-Media
70.3°F
77.9°F

Chiller
50°F
50°F

Net Capacity Increase by TIC, MW

TIC Technology

Wetted-Media
Electric Chiller

36
51
16
37
TIC Reduces On-Site and Grid-Wide Emissions

- Reduces on-site emissions* by increasing the efficiency of the turbine being cooled

- Reduces grid-wide emissions* by reducing the need for operating less-efficient and higher-emission power plants

* lb/kWh of all emissions including, CO$_2$, NOx, Sox
On-Site Net Heat Rate Reduction by TIC

Las Vegas, NV (108°F and 8.6% RH): Solid
Anniston, AL (95°F and 42.5% RH): Shaded
Cooled Air Temperatures:
- Las Vegas, NV: 70.3°F, 50°F
- Anniston, AL: 77.9°F, 50°F

Net Heat Rate Reduction by TIC, Btu/kWh:
- Wetted-Media: 221
- Electric Chiller: 264
- Wetted-Media: 98
- Electric Chiller: 155

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Parasitic Power Load of TIC

7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)
Las Vegas, NV (108°F and 8.6% RH): Solid
Anniston, AL (95°F and 42.5 RH): Shaded
Cooled Air Temperatures: Wetted-Media Chiller
Las Vegas, NV 70.3°F 50°F
Anniston, AL 77.9°F 50°F

TIC Parasitic Load, MW

Wetted-Media

Electric Chiller

0.17

4.4

6.2

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Fuel Saving by TIC of a Combined-Cycle Plant

- 7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)
- Las Vegas, NV (108°F and 8.6% RH): Solid
- Anniston, AL (95°F and 42.5% RH): Shaded

Cooled Air Temperatures:

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<tr>
<th>Location</th>
<th>Wetted-Media</th>
<th>Chiller</th>
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<tbody>
<tr>
<td>Las Vegas, NV</td>
<td>70.3</td>
<td>50°F</td>
</tr>
<tr>
<td>Anniston, AL</td>
<td>77.9</td>
<td>50°F</td>
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</table>

Net Fuel Savings by TIC of CC and Avoided Operation of SC, MMBtu/hr:

- Wetted-Media: 116 MMBtu/hr
- Electric Chiller: 167 MMBtu/hr
- Wetted-Media: 50 MMBtu/hr
- Electric Chiller: 37 MMBtu/hr
Grid-Wide NOx Reduction by TIC of a Combined-Cycle System

7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)

Las Vegas, NV (108°F and 8.6% RH): Solid
Anniston, AL (95°F and 42.5 RH): Shaded

Cooled Air Temperatures:
Las Vegas, NV
Wetted-Media 70.3°F
Anniston, AL
Chiller 50°F
Wetted-Media 77.9°F

NOx Reduction by TIC of CC and Avoided Operation of SC, 1,000 lbs./h

Wetted-Media

Electric Chiller

134

93

40

92

TIC Technology
Example

TIC on a nominal 500 MW CC plant eliminates the need for siting a new or operating an existing 75-95 MW SC peaker

- Eliminates costs associated with siting, construction and interconnections of a new plant
- Reduce long lead time for a new plant (TIC requires <1yr)
Example of Monthly Incremental Net Electric Energy Provided by Some of the TIC Technologies (316 MW Cogeneration Plant Near Houston, TX)

Source: D.V. Punwani et. al. Presented at ASHARE 2001
Factors Affecting the Economics of TIC

- TIC Technology
- Annual Operating Hours
- CT Characteristics
- 8,760 Hours Annual Weather Data for the Geographic Location of the CT
- Market Value of the Additional Electric Energy Produced
- Fuel Cost
Examples of the Effect of TIC Technology on Capital Cost for Incremental Capacity

<table>
<thead>
<tr>
<th>Capacity Enhancement Capital Cost, $/MW</th>
<th>No Cooling</th>
<th>Wetted Media</th>
<th>Fogging</th>
<th>Wet Compression</th>
<th>Electric Chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Enhancement Capital Cost, $/MW</td>
<td>832,941</td>
<td>15,660</td>
<td>14,797</td>
<td>95,215</td>
<td>183,421</td>
</tr>
</tbody>
</table>

317 MW Cogeneration System Snapshot at 95°F DB and 80°F WB
Source: Punwani et al ASHRAE Winter Meeting, January 2001
Examples of the Effect of TIC Technology on Capital Cost for Incremental Capacity

7FA in Combined Cycle (1 Gas Turbine and 1 Steam Turbine)
Las Vegas, NV (108°F and 8.6% RH)
Economic Benefits

- Generates more MWh during peak demand periods when electric energy value is high
- Reduces capital cost per unit of the increased generation capacity compared to new power plants
- Reduces fuel cost of electric energy generation compared to the low energy efficiency “peakers”
- Reduces cost for ratepayers by potentially lower capacity payments to be provided by the independent system operators (ISOs) to power producers
Regulators should recognize TIC is a valuable solution to their supply problem during hot weather and
- Use the full potential of existing combustion turbine plants
- Require TIC use before allowing construction of new capacity
- Ensure capacity payments provide appropriate returns for systems using TIC

Policymakers should recognize the value of TIC for reducing emission and
- Exempt the TIC from environmental re-permitting
- Create incentives for plant owners to use TIC technology
Summary

Turbine Inlet Cooling

- Significantly increases CT power output during hot weather
- Multiple options of commercially-proven technologies are available
- Generally economically attractive for the plant owners and rate payers
- Helps reduce emissions and thus, good for the environment
Upcoming TICA Webinars on Best Practices

- June 11, 2014: Wetted-Media Evaporative Cooling
- August 13, 2014: Fogging
- October 8, 2014: Chiller Systems
- December 12, 2014: Thermal Energy Storage
- February 11, 2015: Wet Compression
- April 8, 2015: Hybrid Systems
Dharam V. Punwani
dpunwani@avalonconsulting.com
1-630-983-0883
Q & A