IDE technologies ltd.

Application of GREEN Ice Thermal Storage System for Peaking Gas Turbine Power Plants

Cooling Solutions

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Outline

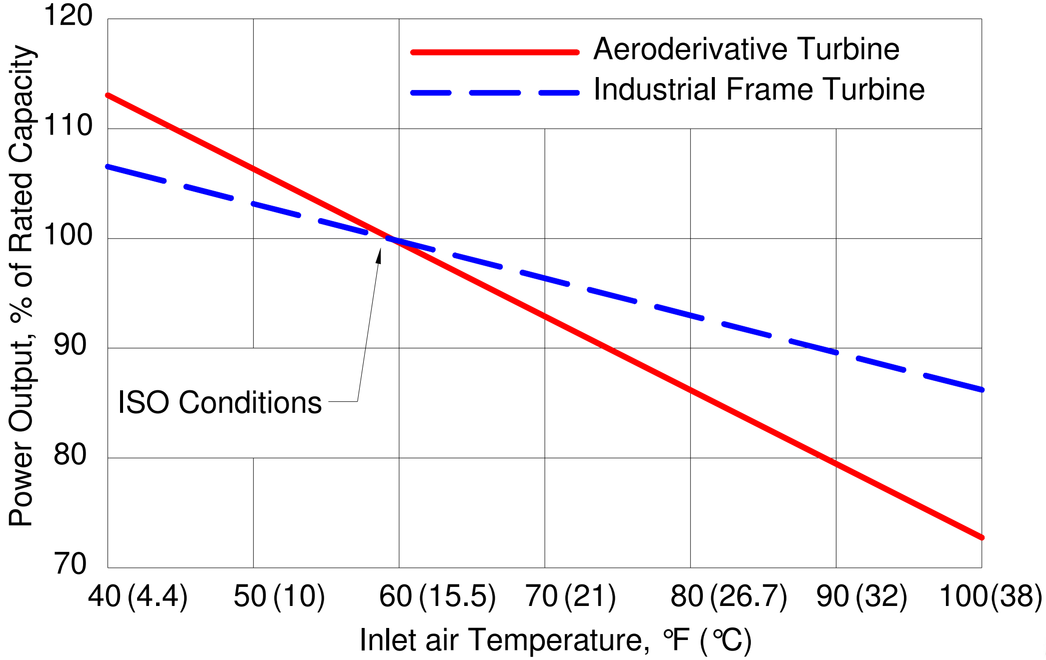
- Introduction to Turbine Inlet Cooling (TIC) – Technologies Overview
- Existing Plant Characteristics
- Thermal Energy Storage (TES) Selection Criteria
  - Chilled Water vs. Static Ice vs. Dynamic Ice
- Vacuum Ice Maker (VIM) Operation
- Results
  - Required modifications
- Conclusions
- Q&A

Terminology

- Ice Slurry
- Vacuum Ice Maker (VIM)
- Thermal Energy Storage (TES)
- “On-Demand” Chillers
- Static Ice
- Dynamic Ice
- Turbine Inlet Cooling (TIC)

Introduction

- Thermal Energy Storage (TES) for Turbine Inlet Cooling (TIC)
  - Combustion Turbine (CT) – ISO rated conditions: 59°F and 14.7psig
- Rate structure; TIC capital cost; Operation & Maintenance, Efficiency, Modularity & Expandability



Introduction

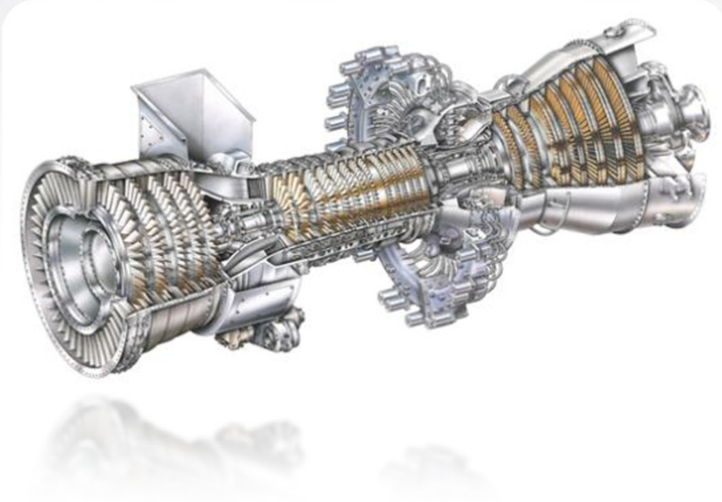
- TIC with Mechanical Chillers
  - "On-Demand" cooling – follows variable load
  - 45°F water supply temperature & de-rated conditions
  - Parasitic power consumption
- Ice Based TES Systems
  - Low temperature refrigerant & very de-rated conditions
  - Heat transfer surface area with high capital cost
  - Internal vs. External melt systems
- Ice Slurry Systems
  - Increased heat transfer without a HT surface area
  - No insulating effect from accumulating ice
  - Variable & Rapid discharge capabilities

Introduction

- TES (any type) Benefits for TIC:
  - Refrigeration equipment smaller capacity & footprint
  - Parasitic load shifted to off-peak hours
  - Revenue recovery maximized during on-peak hours
  - Low water and CT air supply temperatures
  - Increased level of redundancy
  - Variable & rapid discharge (dynamic ice TES systems)

Existing Plant – LM6000 SPRINT™

- LM6000 SPRINT™
  - GT Combustor temp.: 1,600°F
  - Heat Rate: 8,900 Btu/kWh
  - Plant efficiency: ~ 38%
  - SPRINT system: compressor High Pressure injection of demineralized water

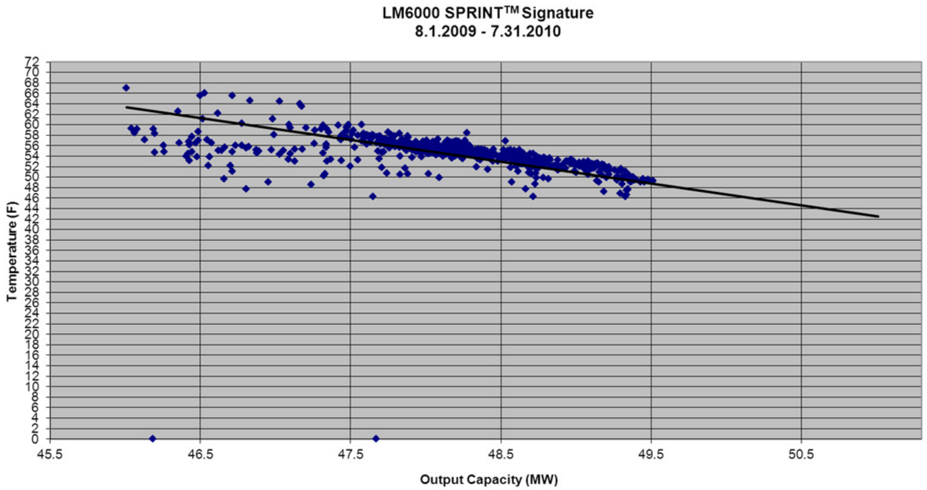


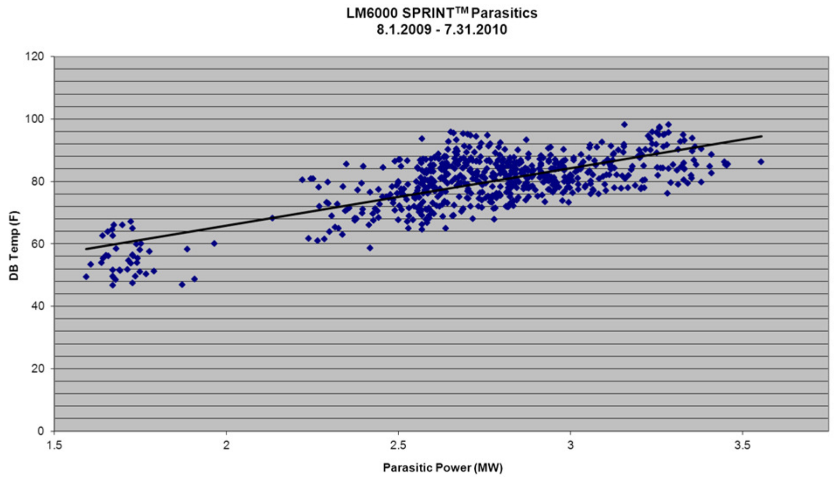
- ASHRAE TIC Guidelines:
  - Ambient temp.: T_{DB}=91°F, T_{WB}=74°F,
  - Optimal inlet air temp.: T_{WB}46°F

$$Q = \dot{m}(h_1 - h_2) = 291\,[\frac{lbs}{\sec}] * 3{,}600\,[\frac{\sec}{hour}] * (37.8[\frac{Btu}{lbs}] - 18.2[\frac{Btu}{lbs}]) * \frac{1}{12{,}000\,[\frac{Btu}{tonR}]} = 1{,}711\ tonR$$

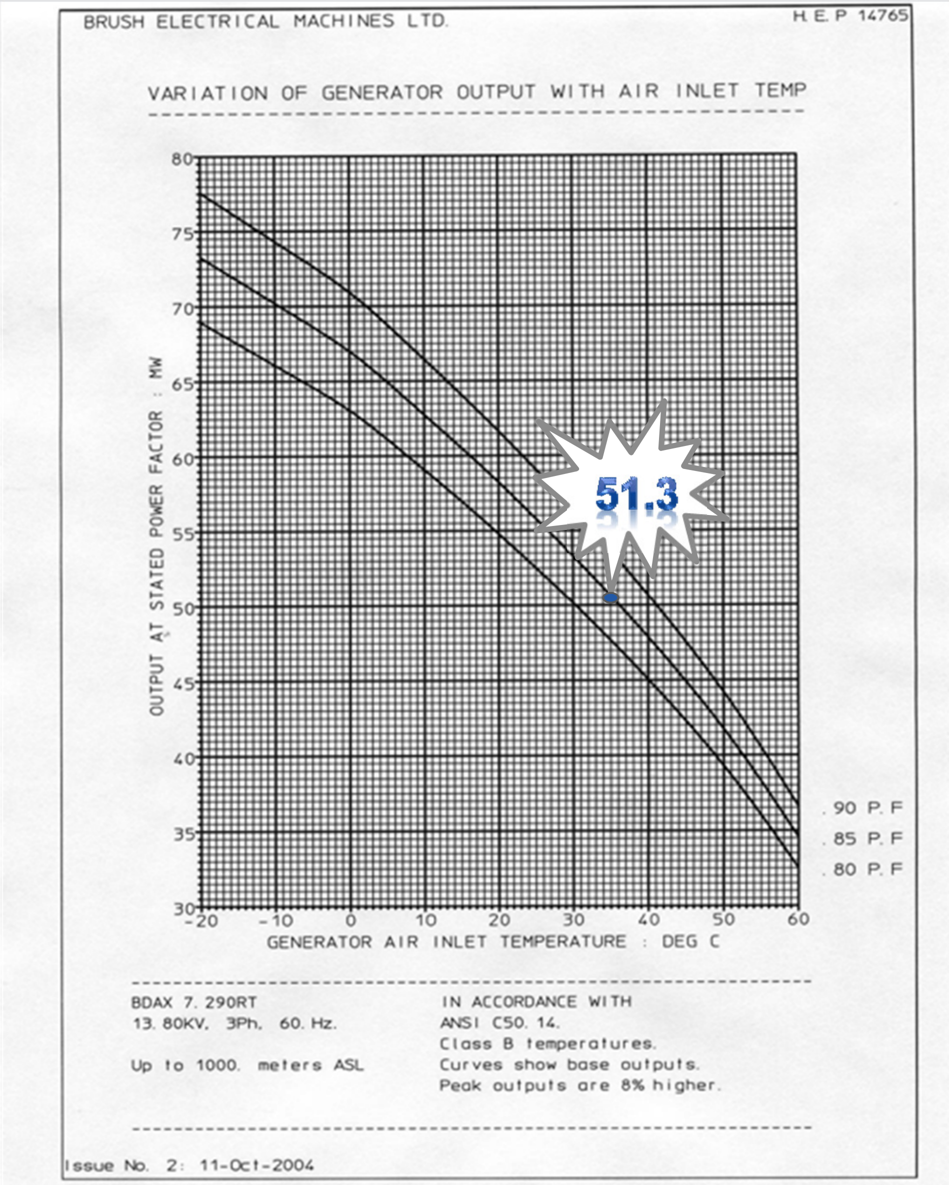
Existing Plant – LM6000 SPRINT™

- Annual hourly data
  - Turbine gross electric power output [MW]
  - Turbine net electric power output [MW]
  - Compressor inlet temperature [°F]
  - Compressor inlet pressure [psig]
  - Ambient T_{DB} [°F] & Relative Humidity [%]





Existing Plant – LM6000 SPRINT™



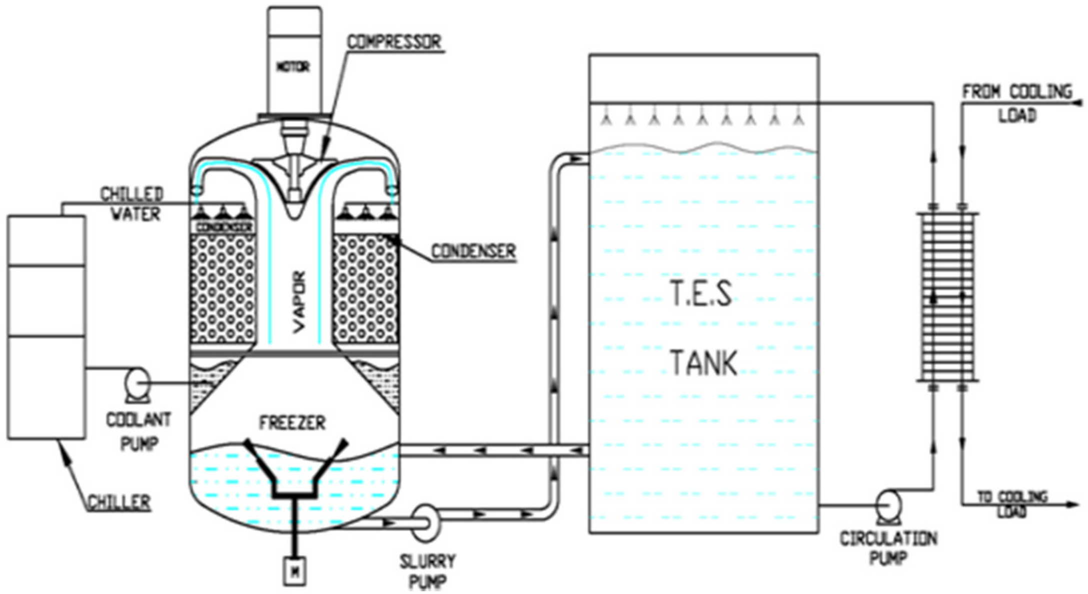
- Compressor Inlet Temp
  - T_{WB}: 46°F
  - Generator limitations
    - T_{WB}: 42°F
    - PF: above 0.85

TES Selection Criteria

Pros	Cons
Chilled Water TES	
• Redundancy	• Complex & expensive TES tank
• Low first cost	• Large TES tank footprint
• Simple integration	• Maximum water supply temp. of 39°F
Static Ice TES	
• Redundancy	• TES Tank with internals and moving parts
• Relatively low first cost	• Very low refrigerant temp.: 14°F - 22°F
• Low supply temperatures	• Specialized refrigerants, e.g. ammonia
	• Limited heat transfer surface area
Dynamic VIM Ice TES	
• Redundancy	• Little known TIC experience
• No internal heat transfer surfaces	• Requires dedicated chillers
• Simple & low cost TES tank	• Large equipment footprint
• Water as only refrigerant	

VIM TES Operation

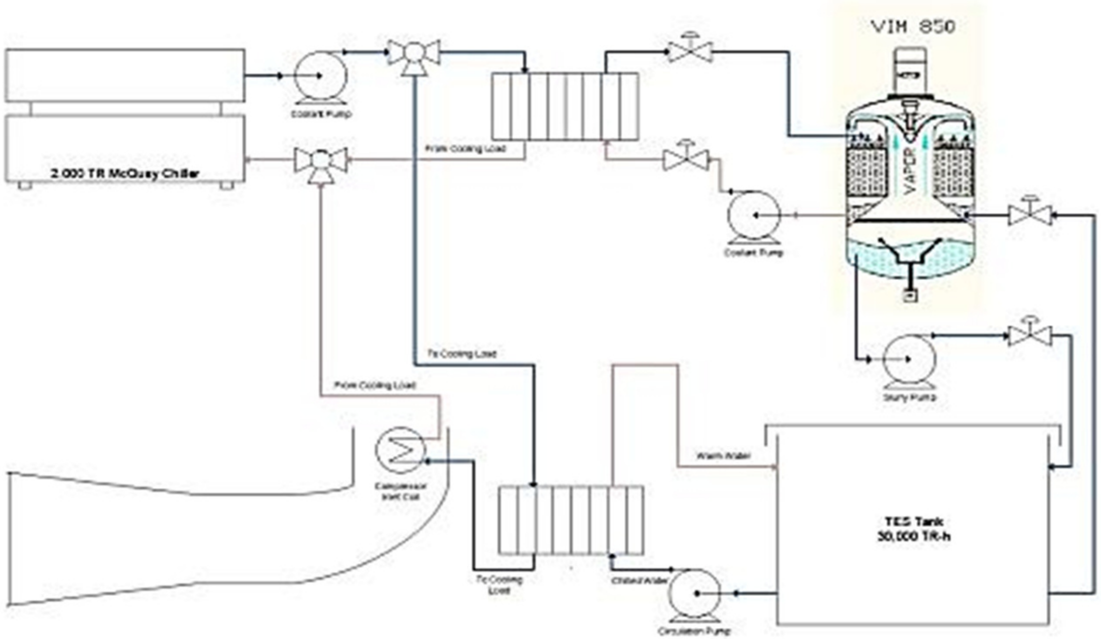
- Process
  - Inside the VIM freezer, water is at "triple point" where all 3 phases exist in equilibrium, exposed to deep vacuum
  - The vacuum forces a small part of the water to evaporate while the remaining water freezes forming Ice Slurry, a water-ice mixture
  - The slurry is pumped from the freezer into the TES tank until ice concentration reaches 50%
- VIM employs water as the only refrigerant – Environmentally friendly – GREEN solution



- Power consumption 0.38kW/Ton (VIM only)
- Pumpble and non-coagulative Ice Slurry
- Small ice crystal size: 0.02– 0.04 inches
- Variable & rapid discharge capabilities

Proposed Configuration

- Existing equipment
  - 2,000 Ton electric-driven centrifugal chiller
- New equipment
  - VIM, TES Tank, HX's, pump, piping & controls



TES Operation Cycle

- Off peak tariff hours: 10:00pm – 8:00am
- Turbine operation duration: 8 hours
  - $Daily\ Cooling\ Demand = 8hours * 1{,}750Ton = 14{,}000Ton$
  - $Weekend\ Cooling\ demand = 5hours * 1{,}750Ton = 8{,}750Ton$

[TR-h]	Mon	Tue	Wed	Thu	Fri	Sat	Sun
TES Cap	30,000	26,000	22,000	18,000	14,000	10,000	20,000
Discharge	14,000	14,000	14,000	14,000	14,000	8,800	8,800
Residual	16,000	12,000	8,000	4,000	0	1,200	11,200
Charge	10,000	10,000	10,000	10,000	10,000	18,800	18,800
Final Cap	26,000	22,000	18,000	14,000	10,000	20,000	30,000

TIC Systems Power Consumption

- TES Charge cycle (off-peak)

Item	Qty	Power Consumption (kW)
VIM System	1	382
Supporting Chiller	1	868
Coolant Pump	1	55
Total:		1,305

- TES Discharge cycle (on-peak)

Item	Qty	Power Consumption (kW)
Circulation Pump	1	75
Coolant Pump	1	75
Total:		150

Results

- Required modifications
  - SPRINT^{TM}: Full injection
  - Turbine's controls system
- Load shift (on-peak to off-peak): about 2 MW
- Increase in turbine's electric output: about 4.3 MW

  due to the very low inlet temp.: 42 °F
- Total gross electric power output: 51.3 MW

  about 12% increase in electric power output

Results

Operation Data Summary	
Discharge Period (weekdays, on-peak)	8-hours
Annual estimated recharge hours (VIM Operation hours, off-pk)	2,628
Charge cycle power consumption, off-peak (MW)	1.305
Annual power consumption to recharge TES, off-peak (MW-h)	3,430
Annual estimated discharge hours (on-peak)	1,680
Discharge cycle power consumption, on-peak (MW)	0.15
Annual power consumption to discharge TES, on-peak (MW-h)	252
Avoided parasitic power consumption, on-peak (MW)	2
Annual avoided parasitic power consumption, on-peak (MW-h)	3,360
Estimated added power capacity, on-peak (MW)	4.3
Annual added electric power output (MW-h)	7,224
Total annual increase in net off-peak consumption (MW-h)	3,430
Total annual increase in net on-peak production (MW-h)	10,584

Conclusion

- Current configuration
  - "On-demand" chiller: cooling demand 1,711 Tons during on-peak hours
- Proposed configuration
  - VIM TES: cooling demand only 1,100 Tons, and shifted to be during off-peak hours
  - Improved chiller seasonal efficiency
- Benefits:
  - *Electric output increase: about 12%*
  - *Chiller power consumption reduced: about 25%*
  - *Increased level of redundancy*
  - *Environmentally friendly GREEN solution*

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Q & A