The Impact of Air Conditioning Design on The Power Plant

Presented at:

POWER-GEN MIIDDLE EAST
Manama, Kingdom of Bahrain
13 – 15 September 2004

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ISO 9001:2000

FORWARD

The region comprised of the Gulf Cooperation Council (GCC) which includes Bahrain, Iran, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE, is one of the most economically vibrant areas in the world. In recent years the number of large development projects have grown exponentially. New construction has resulted in millions of refrigeration tons (kW-thermal) of new air-conditioning equipment being installed or planned. Over the summer months more than 50% of the electric demand comes from air-conditioning loads. During "peak" electric demand hours closer to 100% of the "peak" load can be attributed to air-conditioning. New power plants are being planned and built to meet this electric demand.

Gas turbines (GT) are the current power generation method of choice for the majority of power needs in the Middle East. One major disadvantage of this technology is the degradation of capacity and heat rate during months with hot weather days. The highest electric demand load, primarily from air-conditioning on hot weather days, is at a time coincident with the least amount of power available from the GT.

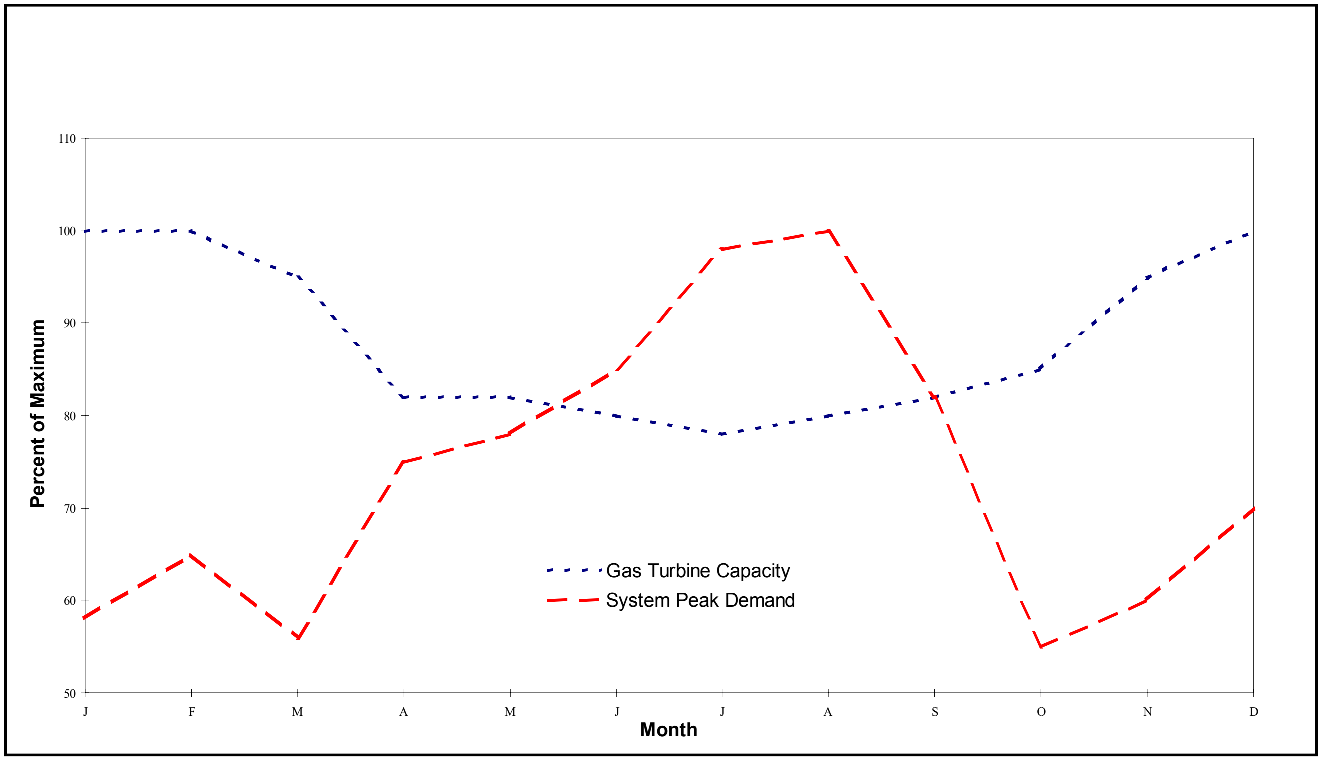

Figure 1. Generic Electric System Load and GT Capacity vs. Temperature Curves

When air conditioning design considerations are being made for a large new facility, the availability of power is often taken for granted. More than just the availability of power, the decisions made for air-conditioning have an impact on the power plant operation.

This paper reviews considerations for the air-conditioning of a large new complex and the resulting impact on GT plant economics. Specific attention will be given to changes and trends resulting from technology choices and the reduced costs of central plant chillers.

Thermal Energy Storage (TES) can also make a difference. For the purposes of keeping the principles of these remarks less complicated, TES is commented separately after the case study.

INTRODUCTION

Currently there are over one billion (1,000,000) square feet of large complexes under development in the region comprised of the GCC. The air-conditioning requirements will be in the range of three million (3,000,000) tons of refrigeration capacity. The newly connected power needed to run the air-conditioning has a range from two and one-half (2.5) to five (5) Giga-watts, depending on the air-conditioning design. This is about the current generating capacity of Iraq and greater than the electric demand in several member countries of the GCC.

Where is the power going to come from to run the air-conditioning? Air-conditioning loads in the GCC account for well over 50% of the electric power demand at their power plants and nearly 100% of the peak power of each Electric Utility. What do the Owners consider in making a decision regarding the air-conditioning in the GCC? Usually, not enough consideration is given to factors other than the capital cost.

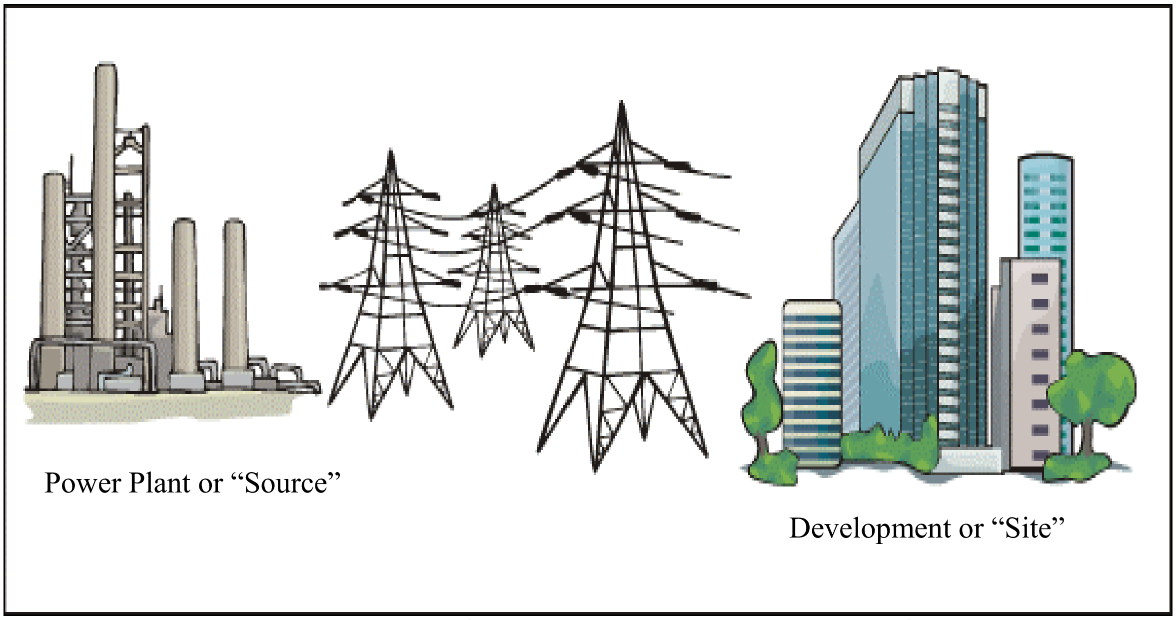

Figure 2. An illustration of "Where" air-conditioning power comes from

What should an Owner consider for air-conditioning? The answer is not the simple "the cheapest as long as it works." What is most often overlooked in the GCC is that the simple "lowest cost" decision has an impact on the development or "site" economics. Not only the site, but also the power plant or "source" economics are also affected. How does the "site" decision for air-conditioning affect the "source"?

To determine "site to source" economics, the following example is presented. A new large development of six million square feet (6,000,000 sq. ft.) is to be built in the UAE. The multi-use facility includes residences, hotels and offices. The building load analysis suggests a 20,000-ton refrigeration load.

Two cases for air-conditioning are evaluated: (1) past water-cooled central plant design and (2) an optimal water-cooled central plant design. These cases affect the decision of the owner and will explore the "site to source" capital cost, energy cost and environmental impact.

SITE ANALYSIS

All air-conditioning systems are not equal. To demonstrate the range of differences, an air-cooled de-centralized system could be considered, however, the majority of large systems are now based on water-cooled central plant design. An air-cooled system is not being considered. The fact is, with the exception of water not being available, it is now generally understood and accepted that large air cooled systems are too expensive to operate and maintain, compared to water cooled central systems. An air-cooled plant operating in the GCC could easily require two times (200%) the power of a water-cooled central plant design.

Assumptions made for the development are:

- Ambient (Weather) Conditions for Dubai, UAE
- Modeling Tool: Commercial Chiller Plant Analyzer
- Yearly Analysis (not peak or bin)
- Account for all central plant components

20,000 ton Case Example	
Case 1 (past)	**Case 2 (future)**
• Evaporators/condensers in parallel	• Evaporators/condensers in series, counter-flow
• 10 Chillers	• 8 Chillers
• Primary-Secondary chilled water system	• Variable-primary chilled water system
• 1.010 kW/ton at specified conditions*	• 0.823 kW/ton at specified conditions*
* Efficiency ratings are given for the complete central plant system including the chillers, pumps, cooling tower fans and general central plant auxiliaries.	

Table 1. Water Cooled Central Plant Comparison

- The attention of these two examples is not to be made on the differences of the system components.
- These two examples can be demonstrated by several available “chiller plant analyzer” tools from the major OEM chiller manufacturers.
- A consulting engineer can confirm the results.

The purpose of the site analysis is to establish a reasonable, if even small difference in performance. What is the difference of the rated efficiency between Case 1 and Case 2? For the given 20,000 ton example the total difference in “peak” power need is:

(1.010 kw/ton – 0.823 kW/ton) X 20,000 tons = ***3740 kW (3.74 MW)***

Site Economic Summary

“Life cycle cost, net present value;” why spend today for savings tomorrow? As an owner and as an investor, one must consider the 30-year plant life impact. Before reviewing the source impact at the power plant, a simple conservative 15-year “net present value” is provided in Table 2.

Additional economic assumptions made for the development are:

- Cost of electricity: $ 0.0543 per kWh
- Cost of water: $ 0.0068 / gallon of water

20,000 ton A/C Economic Summary (US Dollars)		
	Case 1 (past)	Case 2 (future)
Central Plant Capacity (tons):	20,000	20,000
Central Plant Efficiency (kW/ton):	1.010	0.823
Annual Equivalent Full Load Operation Hours:	3725	3725
Annual Electric Cost:	$4,087,975	$3,316,355
Annual Make-up Water Cost:	$1,738,216	$1,634,278
Total Annual Utility Cost:	$5,826,191	$4,950,633
15 Year Net Present Value, Case 2 compared to Case 1:		$7,494,393

Table 2. A simple Net Present Value (NPV) summary (US Dollars)

An alternative way to look at the 15-year net present value is to change it to the capital cost for the Water Cooled Central Plant.

$7,494,393/20,000 tons = **$374.72/ton**

Simply stated, the $375/ton is a large part of the water-cooled central plant cost. An optimally designed plant can pay for itself, compared to alternative systems, over the 30-year life of the plant.

Figure 3. A new "packaged" central plant incorporating Case 2 principles

SOURCE ANALYSIS

Figure 1 actually shows three components. In addition to the energy use at the site and the source energy required to generate the required electricity, there is the often overlooked, transmission losses. The energy used to get the electricity across the power lines from the power plant to the user. Energy is lost due to resistance in power lines. Transmission or “line losses” include the transmission voltage and distance, weather, the time of day and more. Line losses are highest when the lines are fully loaded and when the ambient temperature is hotter which is coincident with the highest air-conditioning demand.

For simplicity, a general assumption is made for this discussion. Line losses, while they vary, are considered to be 10%. The power needed at the source (power plant), is assumed 10% greater than the demand for electricity at the site. Also as stated, thermal energy storage (TES) is discussed separately. With TES, line losses have a greater impact due to the time shifting of load.

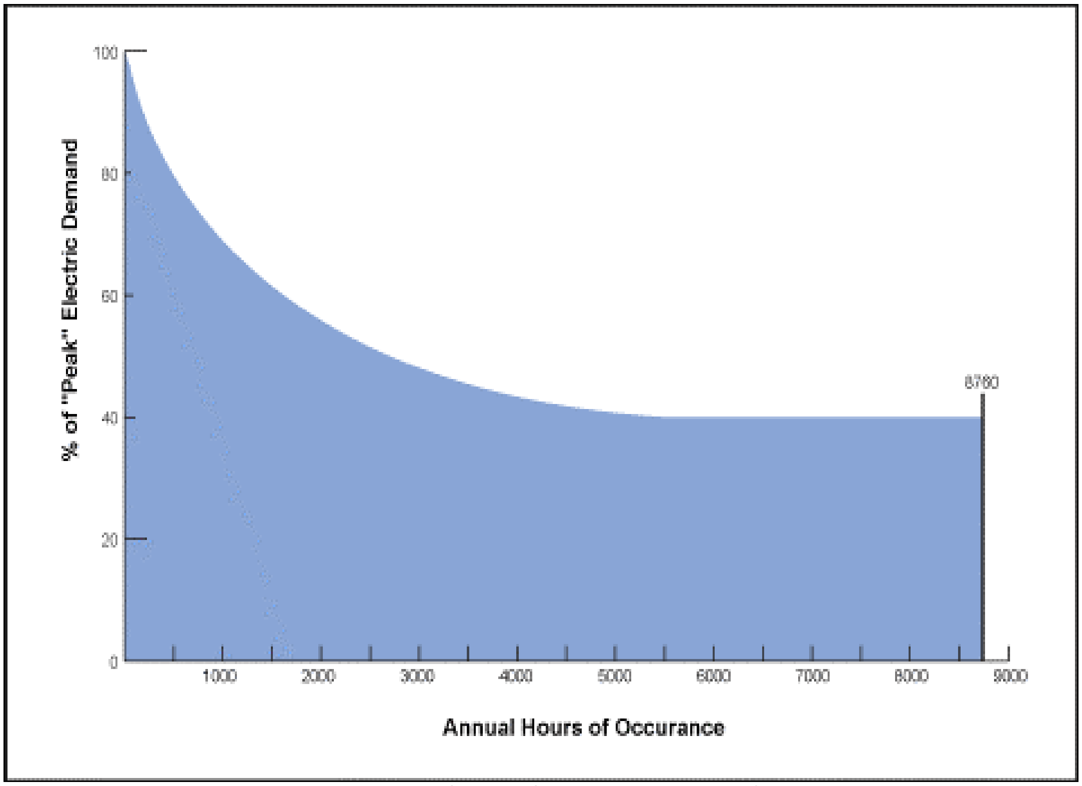

Figure 4. Typical Total Source Capacity vs. Hours of Annual Use

In the 6,000,000 square foot, 20,000-ton air-conditioning example, the difference in efficiency at the site between Case 1 and Case 2 is 0.187 kW/ton or 3740 kW. In addition to the site life cycle cost savings, what is the impact at the source, the power plant? Figure 4 above shows the typical electric demand hours of total source power. “Peak” power is only required about 20% of the year, coincident, and driven, by air-conditioning demand. For this reason power plant capital cost and heat rate is conservatively assumed using recent simple cycle new construction.

Case 1 and Case 2 study are brought back to the source, the power plant, in the following Tables. The Tables below consider the source capital cost, energy cost, and the environmental impacts.

Source Capital Cost (US Dollars) for the 20,000 ton A/C Plant		
	Case 1 (past)	**Case 2 (future)**
Central Plant Capacity (tons):	20,000	20,000
Central Plant Efficiency (kW/ton):	1.010	0.823
Source Power Required including “line losses” (kW):	22,220	18,100
Average Capital Cost of recent Source Power at $300/kw:	$6,666,000	$5,430,000
Capital Cost, Case 2 compared to Case 1, in Savings:		**(savings)$1,236,000**

Table 3. A simple Source Capital Cost Savings between average and “high” efficiency systems

Annual Source Energy Cost (US Dollars) for the 20,000 ton A/C Plant		
	Case 1 (past)	**Case 2 (future)**
Central Plant Capacity (tons):	20,000	20,000
Central Plant Efficiency (kW/ton):	1.010	0.823
Source Power Required including “line losses (kW):	22,220	18,100
Annual Equivalent Full Load Operation Hours:	3,725	3,725
Annual Source Energy Value based on an assumed average heat rate of 10,800 BTU/kWHr and $1.39 $/mmBTU Gas Cost:	$1,242,536	$1,012,147
Annual Energy Cost, Case 2 compared to Case 1, in Savings:		**(savings)$230,389**
Simple 15 Year NPV, Case 2 compared to Case 1 ($/ton):		**(savings)$173/ton**

Table 4. An example of Energy Cost Savings between average and “high” efficiency systems.

Environmental Impact at the Source Capital Cost (NOx and CO Emmissions) for the 20,000 ton A/C Plant		
	Case 1 (past)	**Case 2 (future)**
Central Plant Capacity (tons):	20,000	20,000
Central Plant Efficiency (kW/ton):	1.010	0.823
Source Power Required including “line losses (kW):	22,220	18,100
Annual Equivalent Full Load Operation Hours:	3,725	3,725
Annual Source (Power Plant) NOx emissions based on an assumed gas turbine average emission of 1.68 LBS/HR/MW:	139,053 LBS	113,270 LBS
Annual Source (Power Plant) CO emissions based on an assumed gas turbine average emission 0.86 LBS/HR/MW:	71,182 LBS	57,983 LBS
Annual Source NOx emissions, Case 2 compared to Case 1:		**(reduction)25,783LBS**
Annual Source CO emissions, Case 2 compared to Case 1		**(reduction)13,399LBS**

Table 5. An example of the Environmental Impact between average and “high” efficiency systems

Gas Turbine Inlet Air Cooling

The above Source Analysis was done without the benefit of Gas Turbine Inlet Air Cooling. Cooling and de-humidifying the gas turbine compressor intake air on a hot day would result in a large increase in power and efficiency at the Source. Using a high efficiency air-conditioning system to cool the intake air provides the lowest life cycle cost solution of commercially available technologies in the market.

Reference is made to last years PGME 2003 paper titled "*ASSET OPTIMIZATION OFNEW POWER PROJECTS WITH GAS TURBINE INLET AIR COOLING"* for a more complete understanding of inlet air cooling. A summary of benefits is offered here, however, the purpose of this paper is to demonstrate the impact typical on new and planned power plants in the region. Despite the proven technology success from gas turbine inlet air-cooling systems in operation globally for ten (10) to fifteen (15) years, applications in the Middle East region have been few. For this reason, the above Source Analysis has been made assuming un-cooled plant

For consideration:

- In all cases studied gas turbine inlet air cooling was found to be more cost effective than simply building additional non-cooled power plant capacity in the GCC region.
- Evaporative or fog cooling methods can provide a significant amount of low cost capacity to the power plant, but not nearly as much as a high efficiency air-conditioning system.
- A high efficiency "packaged" air-conditioning system will lower the simple cycle power plant heat rate by 3% to 4% and increase capacity by 30% (depending on the GT type) on a "peak" 50°C ambient summer day.

Figure 5. A Gas Turbine Inlet Air Cooling System (bottom right) shown at a 500 MW Combined Cycle Plant

THERMAL ENERGY STORAGE

Thermal Energy Storage (TES) can be applied at the Site and the Source, the building and the power plant. First, what is TES? TES systems add or remove heat to a storage medium for use at another time. For air-conditioning systems, some or all of the work of the chillers is done during nighttime hours storing energy in a storage tank. In practice today, the energy storage medium for Site (building) applications is most often ice or water. For gas turbine inlet air-cooling at the Source, chilled water storage is the most common, having the highest efficiency at the chiller plant. The difference is that at a building there can be some fan energy savings that justify the chiller energy penalty to make ice. Figure 6 below illustrates the concept of TES at the Site. At the power plant TES operates without a fan, air is "sucked" into the gas turbine.

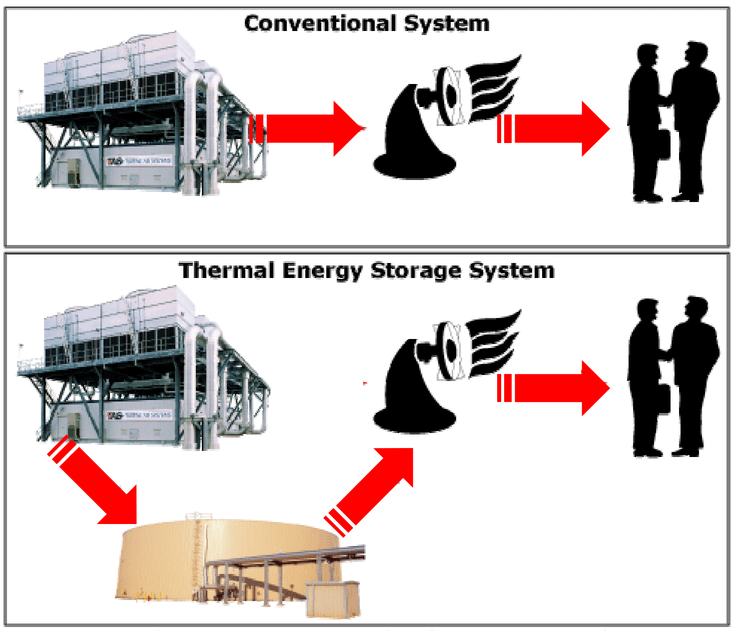

Figure 6. Concept illustration of TES applied at the Site

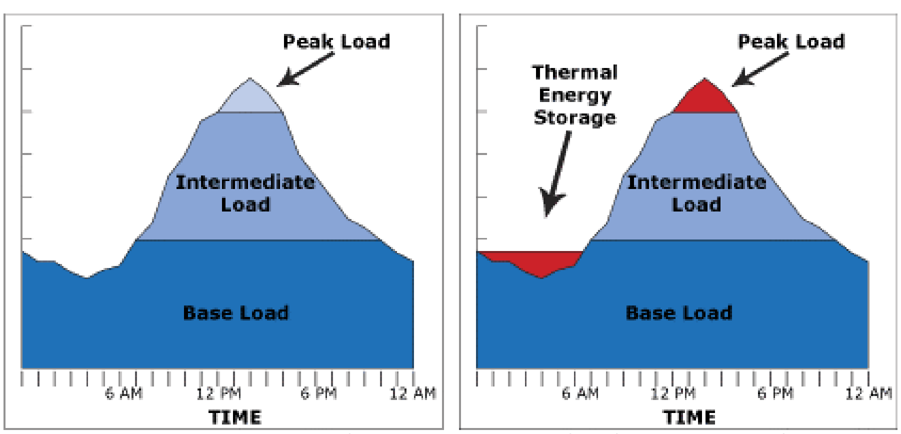

Figure 7. Example daily electric load profile showing the "shift" of "peak" power from day to night

What is the purpose of TES? Some or all of the daytime power and energy required for air-conditioning is moved to night. This shift will reduce capital cost at both the Site and the Source. The shift can also reduce the energy cost. At the Site, the connected load is reduced. Back to the Source, “line losses” are reduced. At the Source, the gas turbine has more available capacity at “peak” times because some or all of the work of chillers has been done before the electric demand.

Again, for purposes of this paper, TES is highlighted as another consideration for Site and Source optimization. Additional Site and Source analysis can be done to demonstrate the benefits but is not included in this paper.

CONCLUSIONS

“Site to Source” benefits from appropriate design evaluation of air-conditioning are critical to system optimization at both ends, the need for electricity and where does it come from. Capital cost, energy usage, life cycle cost and net present value are all improved in the total “Site to Source” economics. Before making recommendations a summary of benefit considerations is given.

Site Benefit Summary

The Capital Cost of a large air-conditioning project should not be the driving factor in an Owner’s decision in selecting the system. Site life cycle cost and net present value are improved significantly with high efficiency air-conditioning systems.

For a given example of a new 20,000 ton water cooled central plant for air-conditioning of a multi-use complex, high efficiency design has an estimated value of US $374/ton on a 15 year net present value; over a 30 year central plant life (US $750/ton) the original purchase price a “packaged” water cooled central plant is recovered (based on GCC ambient and operating conditions).

“Packaged” Central plants optimize high efficiency air-conditioning systems by lowering capital cost while incorporating high efficiency design.

Source Benefit Summary

The selection by an Owner on the air-conditioning design and system for a large project, or Site, has a direct impact on the Source, the power plant. From the 20,000 ton example water cooled central plant example, a capital cost savings at the Source is over $60/ton:

$1,236,000 for this 20,000 ton Case Study
$300 per kW in deferred capital cost

The example of a new 20,000 ton water cooled central plant for air-conditioning of a multi-use complex, high efficiency design has an approximate value of US$ 173/ton for the Source energy on a 15 year net present value; more than the purchase price of chillers in less than the “half-life” of the central plant.

There is an environmental impact associated with the decision by the Owner for air-conditioning. High efficiency air-conditioning systems reduce Source emissions.

Other Benefits Summary

Gas Turbine Inlet Air Cooling changes the Source performance at a simple, combined cycle and gas turbine based desalination plants. Efficiency improvements of 3% plus can be realized. Capacity increases of 30%, or more, reducing the $/kW of a power plant capital cost by 10%, will be recognized in new construction using gas turbine inlet air cooling with high efficiency air-conditioning.

Thermal Energy Storage (TES) affects both the Site and the Source. Capital savings can be made at both Site and Source. Depending on load factors and design, energy cost savings can be significant at both the Site and Source.

RECOMMENDATIONS

It takes Government Regulatory or a common party to “marry” Site and Source. An Owner has the incentive based on life cycle cost to generally choose a high efficiency air-conditioning system over the “cheapest.” Source providers, typically the Government in the GCC, should consider:

At the Site Air Conditioning Loads:

District Energy cooling technology should be required for all new large residential and commercial developments including hospitals, campuses, malls, etc.to improve the electrical demand curve.A full economic analysis should be undertaken for the evaluation of water-cooled technologies, which are much more energy efficient than air-cooled technologies.

Electricity ministries either set stringent national minimum efficiency standards for air-conditioning systems (kW / ton); or that high interconnect tariffs ($ / kW) be implemented to provide sufficient economic incentive to building higher efficiency refrigeration systems, already typical in many European countries.

At the Source Power Plants:

All new gas-turbine based power sources, whether simple cycle “peakers”, combined cycle plants, or desalinization plants, should be equipped with front-end turbine inlet refrigeration technology, so that the power supply can more closely follow the power demand.

In the development of plans for new power generation sources to meet summer peaking needs, full economic consideration be given to the retrofit of turbine inlet cooling technologies to pre-existing gas turbine plants as a new source of peaking power.

Thermal Energy Storage (TES) technology for inlet refrigeration can be applied at new and existing gas turbine power stations to help improve the supply curve of the power grid.

Other Considerations:

Governments that encourage the use of TES for air-conditioning, thereby improving the demand curve of the electrical grid, could provide sufficient economic incentives. Such an incentive could be as simple as the dismissal of interconnect charges for electrical air-conditioning loads that are only operated during off-peak periods.

Governments should embrace the proven technology of Day / Night electrical metering, and enact peak electrical tariffs to encourage the use of off-peak power and discourage the use of on-peak power.

BIOGRAPHY

Christopher M. Landry is a Director for Turbine Air Systems, Ltd. (TAS) of Houston, Texas, USA. TAS is the world-leading supplier of gas turbine inlet air cooling solutions for the energy industry and a provider of packaged central plants for cooling applications. His work at TAS involves business development, system sales and sales management in the Southeast USA, Europe, Africa, India and Middle East regions. Mr. Landry began his career teaching at the University of Wisconsin. Over the years he has lived in Saudi Arabia negotiating contracts and licensing agreements for a TRANE Company Licensee, developed and implemented a business plan of a new gas turbine inlet air-cooling product line for the Henry Vogt Machine Company and provided field technical services and consulting in the power industry.

Mr. Landry has held Chair positions for ASHRAE and a Board position for the Association of Energy Engineers. He holds a Bachelor of Science in Mechanical Engineering from the University of Wisconsin (USA).