# Unique Combined-Cycle Design Caters to Plants with Cyclical Demand Profiles

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Cyclical load profiles present unique design challenges for power plant developers, particularly for medium-sized facilities (200-300 MW nominal output). Black Hills Energy's Las Vegas Co-generation II power plant showcases a combined-cycle facility with unique design principles, equipment configurations and operational procedures to optimize load response.

The plant, which consists of four GE LM6000 gas turbines, four unfired waste-heat once-through steam generators (OTSGs) and two steam turbine generators, is designed to operate for 16 hours and shut down for 8 hours during each 24-hour period. The facility is scheduled to come on-line in late 2002, and power will be sold to Nevada Power Co.

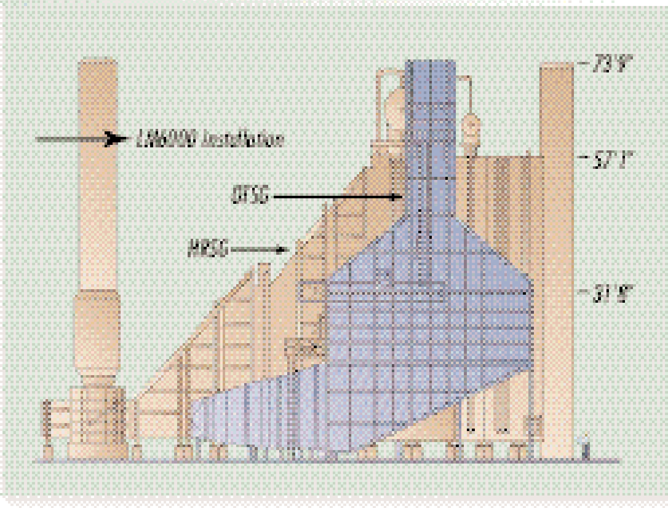
Las Vegas Co-gen II provided an opportunity to develop an economical design approach for a power plant subject to cyclical load demand. Although combined-cycle power plants using the Frame 7F-type machines are more efficient from a thermal standpoint, they require longer startup and shutdown periods. By basing the design on an aeroderivative engine in combined-cycle configuration, cycle efficiency can be maintained at an acceptable level by using the OTSG, and startup and shutdown periods can be minimized because of the LM6000's rapid response characteristics. Gas turbine performance is further enhanced using spray intercooling, fogging, and chilled water systems.

When compared to a combined-cycle power plant configured with one Frame 7F-type gas turbine and one steam turbine generator (for power production of 200-300 MW), the proposed configuration is an excellent choice for cycling units for several reasons:

- *Improved thermal efficiency during turndown plant operation (e.g., when shutting down a train).*
- *Reduced startup and shutdown periods (by using the LM6000 in conjunction with the OTSG, which can operate dry without the need for a bypass stack or diverter valve when SCR is not installed)*
- *Improved overall plant reliability (limited loss of power due to the failure of any one machine)*

FIGURE 1

OTSG VS. HRSG FOOTPRINT




## Basic Design Parameters

A number of constraints and limitations impacted the design of the Las Vegas Co-generation II facility.

The total plant area available for the combined-cycle units was limited to four acres, with limited property depth along the drive train axis. The vertical design of the OTSG, therefore, was instrumental in reducing the land space required. The OTSG length is only 75 feet, compared with 115 feet for a heat recovery steam generator (HRSG) at the same thermal duty.

Stack height, which was limited to 100 feet, presented another challenge. When compared to a conventional HRSG, meeting the height limitation with the once-through steam generator was more difficult. Since a third pressure level would have added additional height, IST designed the OTSG with two pressure levels. Each pressure level coil was designed with the maximum amount of surface area in order to maximize heat recovery. To meet the permitted emission levels of 2 ppm $NO_x$ and CO (15 percent $O_2$ dry), IST had to incorporate the $NO_x$ and CO catalysts into the OTSG design, which was a new design for IST. The catalysts are positioned horizontally downstream of the first HP coil section.

To conserve additional space, the main step-up transformers were designed to accommodate the load from two gas turbines and the steam turbine (instead of one step-up transformer for each of the generators). This deci-

FIGURE 2
FOGGING SYSTEM PERFORMANCE CURVES

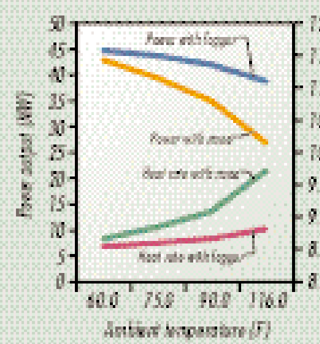
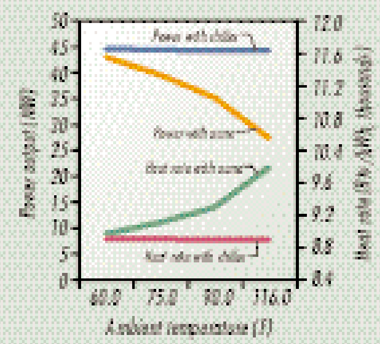



FIGURE 3
CHILLING SYSTEM PERFORMANCE CURVES




sion significantly reduced the space and cost for transformers and switchgear equipment.

The plant achieves similar savings by using fogging and chillers in tandem. Each chiller services two gas turbines, with the extra thermal duty provided by the gas turbine inlet air fogging system.

Further, low allowable sound levels required the installation of a 14-foot high sound wall around the entire facility. By positioning the steam turbine between the two gas turbines, all steam piping is located between the gas turbine and OTSG trains, thereby creating a sound barrier and reducing the sound level.

## OTSG ADVANTAGES

The project team selected a once-through steam generator over a heat recovery steam generator for several other reasons. Most conventional HRSGs use carbon steel as the tube material. Carbon steel, however, loses strength at elevated temperatures, necessitating the use of bypass stacks and diverter valves to prevent the hot exhaust from damaging the tubes during dry running conditions. In OTSGs, the use of high-nickel Incoloy 800 and 825 alloy tube material, which maintains substantial strength and corrosion resistance at high temperatures, permits full dry running without the need for a bypass stack or diverter valve. This allows the OTSG to operate dry for long periods of time with the gas turbine at full power and to also initiate operation at a hot condition under gas turbine full gas flow conditions. For this specific project, there is a temperature limitation for the SCR that only allows the gas turbine to go up to 75 percent load with zero water/steam flow to the OTSG. However, if a high-temperature SCR is installed, the OTSG could allow dry operation at gas turbine full load.

In some climates, the ability to start dry allows the exhaust of the gas turbine to warm the tubes above freezing before introducing water. Loss of feedwater or any other problems with the steam systems, therefore, do not require shutdown of the gas turbine.

OTSGs configured for combined-cycle or cogeneration operation are typically arranged as vertical flow/horizontal tube systems. The horizontal tube configuration results in a smaller footprint, pushing the units vertically rather than horizontally. Figure 1 compares the overall size of an LM6000 40MW OTSG with that of a comparable LM6000 40MW HRSG. The footprint of the OTSG in the foreground is significantly smaller than that of the HRSG in the background.

An OTSG provides another performance benefit related to water usage. Since there is no blowdown, savings are realized in make-up water requirements, which makes the plant even more economical.

## MULTI-COOLING

Multiple cooling systems are used to optimize performance at Las Vegas Cogeneration II. The plant utilizes fogging, chilling, and spray intercooling (SPRINT) systems to reduce the heat rate and to maximize the net power output.

The fogging system is capable of incremental fogging, providing 1-degree steps of cooling through the entire range of 45 F cooling. This allows the fogger to

FIGURE 4
PSYCHROMETRIC CHART SHOWING ZONES OF OPERATION

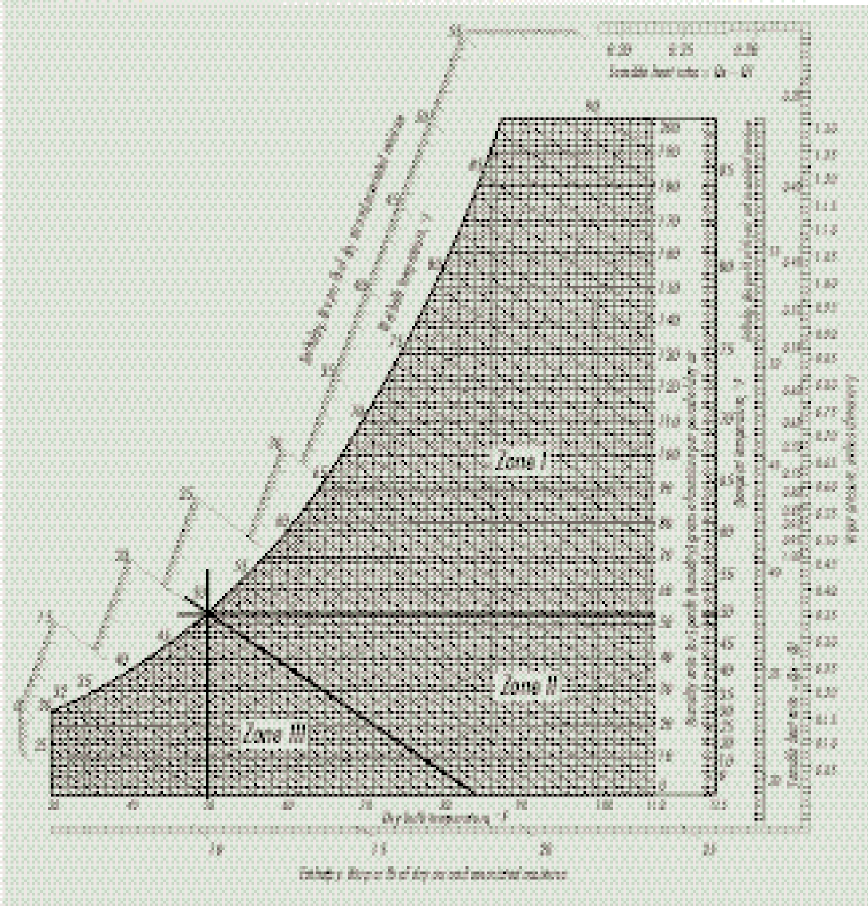


**TABLE 1**
**PLANT PERFORMANCE FOR FOUR COOLING CONFIGURATIONS (116 F DRY BULB, 71 F WET BULB TEMPERATURE)**

| Configuration | Inlet temperature (F) | Gas turbine heat rate (Btu/kWh) | Gas turbine output (kW) | Steam turbine output (kW) | Auxiliary load (kW) | Net output (kW) |
|---|---|---|---|---|---|---|
| Fogging only | 71 | 8,793 | 160,540 | 53,600 | 7,000 | 207,140 |
| Fogging+chilling | 50 | 8,639 | 176,200 | 54,600 | 9,200 | 221,600 |
| Chilling only | 50 | 8,639 | 176,200 | 54,600 | 9,440 | 221,360 |
| No inlet cooling | 116 | 9,560 | 127,300 | 48,700 | 6,700 | 169,300 |

cool the inlet air temperature to the corresponding wet bulb temperature. By reducing the inlet temperature, the fogging system improves the gas turbine's power output, as well as the heat rate. This is particularly useful for this plant's location, where the ambient air is usually hot and dry. Figure 2 illustrates the gas turbine's performance with the fogging system, under the site average ambient conditions. Heat rate and power output are both improved across the temperature range, and the magnitude of the benefit increases as ambient temperature increases.

The chiller is rated at a capacity of 2,200 chilling tons, and has a total chilled water flow rate of 3,300 gpm. This 3,300 gpm is then split in half to serve two gas turbines. In conjunction with the bypass system, the plant can maintain an inlet temperature of 50 F at all applicable conditions. Figure 3 shows the gas turbine's performance with the chilling system, under the site average ambient conditions. Power output and heat rate are maintained at consistent levels throughout the temperature range.

One of the unique features of the Las Vegas plant is that the fogging system was installed upstream of the chilling system and operates in series with chillers. There are three distinct zones of operation (Figure 4). In Zone I, only the inlet chilling system operates. In Zone II, both the fogging system and the chilling system operate. The fogger moistens the inlet air along the constant wet bulb temperature line, until the dew point temperature reaches 50 F. The chiller then further cools the inlet air to 50 F dry bulb temperature. In Zone III, only the fogging system operates.

Zone II, where the fogging+chilling configuration should be applied, merits additional discussion. Table 1 summarizes the predicted plant performance at the high ambient design point in Zone II, for four different configurations. Fogging+chilling is superior to all other configurations in terms of net power output and thermal efficiency. Furthermore, this configuration increases the reliability of the plant because when the chiller is shut down, the fogger is still available.

With all the inlet cooling systems and the short start-up period, Las Vegas Co-gen II will achieve a significantly improved overall heat rate, which makes it comparable to the Frame 7F-type power plants. PE

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