State-of-the-Art Mulberry Cogeneration Facility

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The Mulberry Cogeneration Facility is notable in the power industry. Among the features that make this 120 MW facility stand apart from other power plants are zero discharge wastewater system, an inlet air chilling system, and an extensive Distributed Control System (DCS) for overall plant operation, along with a 25 ppm NO_x dry emission limit on gas fuel for the first 3 years and 15 ppm thereafter.

The Mulberry Cogeneration Facility is owned by Polk Power Partners Ltd. (Central and South West Energy of Dallas and ARK Energy of Laguna Hills, California). The Plant is operated by CSW Energy. Central and South West Services acted as the EPC contractor, and retained Black & Veatch to provide engineering and procurement services, construction liaison, and start-up support.

The facility, located near Bartow, Florida, consists of a single combustion turbine/heat recovery steam generator (HRSG)/steam turbine combined cycle. It provides electric power to nearby Tampa Electric and Florida Power Corporation, and up to 25,000 lb/h of process steam to an adjacent steam host facility that was also developed by the partnership. The Mulberry Cogeneration Facility began commercial operation on August 10, 1994.

PROJECT GOALS

Virtually all independent power projects are developed to provide a fair return on the Owner's investment, and the Mulberry Cogeneration Facility is no exception. Because of a development and construction period that spanned over 4 years, the considerable cost in dollars and personal effort needed to be recovered. However, short-term rewards were not the sole focus of this project. Rather, the Owners wanted to create a plant that would be an asset in their long-term portfolio and be operated and maintained by their personnel.

In addition to fulfilling their contractual obligations to the power purchasers, the steam host created additional reliability requirements for the cogeneration facility. Moreover, the Florida location presented an attractive situation in which hot weather periods were predictable and accompanied by a high demand for power.

Also, a premium price for power was available for delivery during these periods. Being responsible members of the community was another requirement the Owners' placed upon the designers and operators of the facility. Responding to that requirement meant not only complying with all applicable environmental regulations, but also creating a plant that was quiet, aesthetically pleasing, and well maintained. Finally, the plant needed to be a safe, fulfilling place to work so that a talented and caring staff could be recruited, motivated, and retained.

In terms of project implementation, those goals translated to numerous requirements:

- Dry low NO_X control necessary for gas fuel, with water injection to the reaction zone of the combustion turbine combustors allowed when burning fuel oil.

- Station discharges in solid form, except for storm water runoff, with no process water discharge from the site.

- Through the use of integrated control, minimal number of operators and maximum plant availability, thereby enhancing profitability.

DESIGN FEATURES

The 120 MW cogeneration facility was based on a combined cycle configuration that utilized one combustion turbine, one HRSG, and one extraction/condensing steam turbine. The combustion turbine was equipped for dual fuel operation using natural gas and distillate oil as a backup, and was supplied with pulse air filtration to minimize compressor fouling. Cycle heat rejection was accomplished with a conventional cross-flow mechanical draft cooling tower. Makeup water for the steam cycle was supplied from well water via pretreatment and demineralization systems. In addition to these fairly common systems, several special features were built into the plant, each of which is described below:

Zero Discharge

Reflecting the growing concerns about water consumption and wastewater disposal in Florida, the facility incurred a zero discharge requirement as a condition of permitting. This created an interesting design challenge because the plant uses a cooling tower for heat rejection, with the associated large volumes of blowdown water requiring disposal. In other regions of the country, evaporation ponds are a means of achieving zero discharge; however, in Florida, that option was not practical, so a more sophisticated solution was developed.

Zero discharge at the Mulberry Cogeneration Facility is achieved through an integrated water and wastewater management plan. Water treatment systems are designed to produce service water and demineralized water of a quality that minimizes plant wastewater production.

At Mulberry, raw well water is softened before being used for cooling tower makeup. By using softened water, the circulating water system can operate at higher cycles of concentration than if untreated well water was used as makeup water.

Circulating water blowdown flow rates are, in turn, lowered and thus require less treatment capacity in the plant's wastewater treatment system. The makeup demineralizer is furnished with a recycle system to reduce the quantity of wastewater produced during regeneration.

Plant wastewater is segregated as much as practical to allow direct reuse of certain flows without treatment and to accommodate treatment of only concentrated wastewater. More specifically, plant and equipment drains, precipitation runoff, equipment washdown wastes, and boiler blowdown are collected and reused in the plant. No other treatment of these wastes is required.

On the other hand, concentrated wastewater, including cooling tower blowdown, filter backwash wastes, and neutralized chemical wastes, are collected and routed to the wastewater storage tank. These wastewaters are pumped to the zero discharge system for treatment.

After differing technologies and their capital and operating costs were evaluated, the zero discharge system (shown on Figure 1) was selected. Wastewater from the wastewater storage tank is directed to the solids contact unit where lime, soda ash, coagulant, and coagulant aid are added to reduce hardness and silica. Sludge from the clarifier is sent to a sludge thickener for further treatment, concentration, and routing to a filter press. The thickener also treats sludge blowdown produced in the well water pretreatment system.

Periodically, the solids in the filter press are removed and stored in a bin until trucked off-site for disposal in a landfill. Water recovered from the filter press is collected and routed to the wastewater storage tank for further treatment. The treated water from the solids contact unit is directed to gravity filters for suspended solids removal before being treated in the reverse osmosis (RO) system.

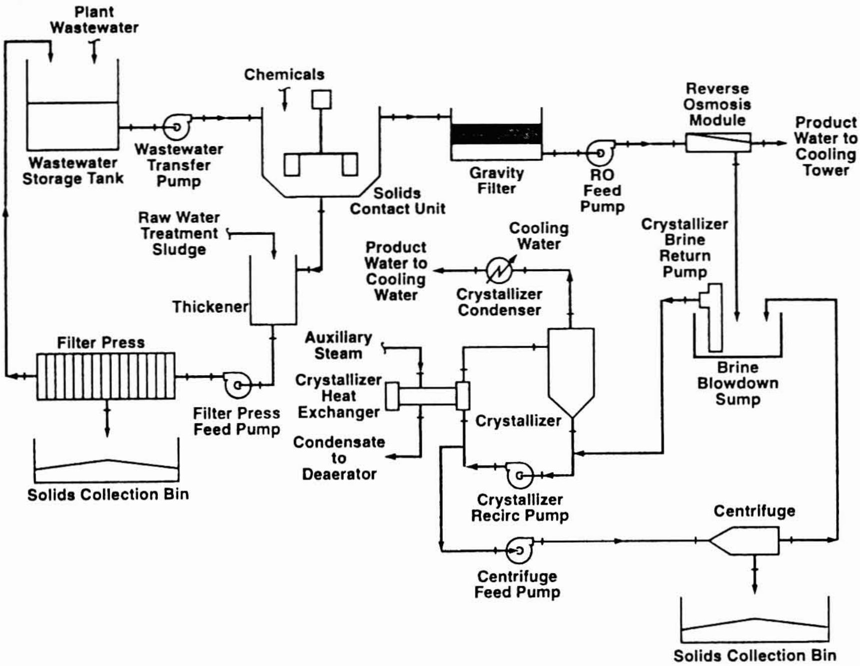

Figure 1. Zero Discharge System

The RO system provides further treatment of the clarified wastewater. The RO feedwater flows through membrane elements under high pressure where the product water diffuses through the membranes, while the reject water and most of the salts exit the membranes as concentrates. The product water is used as cooling tower makeup. The concentrate is routed to the crystallizer via a brine blowdown sump for further treatment.

The concentrated RO reject water is further treated in the crystallizer/evaporator, which produces a relatively clean product water and a concentrated slurry. Steam from the unit's auxiliary steam system is used as the energy source to evaporate the wastewater. Cooling water from the unit's circulating water system is used to condense the crystallizer product water, which is used as cooling tower makeup.

In a centrifuge, the concentrated slurry is separated into liquids and solids. Solids are collected in a storage bin and are trucked to an off-site landfill for disposal. Liquid from the centrifuge is returned to the brine blowdown sump for further treatment.

At full load operation, approximately 2 tons per day of solids are produced from the filter press and the centrifuge. In addition, approximately 120,000 gallons per day of wastewater are treated and recycled in the plant.

Inlet Air Cooling

Because combustion turbines are air breathing machines, turbine performance is significantly affected by ambient conditions. As air temperatures increase, both output and efficiency decline; unfortunately, it is during those high temperature periods that power demands are normally the greatest and the value of electricity the highest. To offset the performance penalty and maximize revenue, various methods are applied to reduce the temperature of the inlet air to the combustion turbine.

The Mulberry Cogeneration Facility incorporates a mechanical compression refrigeration system that uses ammonia as the refrigerant. The inlet air cooling system consists of ammonia compressors, ammonia recirculation equipment, inlet air cooling coils, and an ammonia heat rejection system. The ammonia heat rejection system consists of a cooling tower, fans, and cooling water pumps. Wastewater generated in the inlet air cooling system is treated in the plant zero discharge system.

The inlet air cooling system is capable of reducing the temperature of approximately 1,225,000 lb/h of combustion air flow from 93 F to 53 F. The large compressors, pumps, and heat rejection equipment that constitute the system consume about 3 MW of power when operating, but still allow the net output of the plant to he increased by nearly 7 MW on 93 F day, thereby increasing plant revenues and profitability. The Mulberry Cogeneration Facility is among the first plants of its size to incorporate such technology.

Distributed and Integrated Control System

While distributed control systems are common in modern power plants, the Mulberry control system includes features which reflect the special interests and objectives for the plant. The design objectives for this unit are as follows:

- Provide maximum integration of the various plant controls.
- Minimize the number of operator interface locations.
- Offer commonality of operator interface stations.
- Minimize the integration costs.

Because many components of the combined cycle plant are customarily furnished with self-contained control systems, a method had to be developed to integrate these controls into the overall control system. The starting point for the integrated control system was the balance-of-plant control system which operates all of the steam cycle equipment (excluding the actual steam turbine controls), the well pumps, the fuel supply systems, and the auxiliary electric systems, including the interface to the utility's substation on the plant site. This system also includes the overall plant alarm system, data acquisition, and historical recording for permanent plant records.

A distributed digital control system (DCS) manufactured by Westinghouse Electric Corporation was selected, and all operator interfaces, graphic displays, alarming, and control actions were implemented through a series of CRT displays. The CRT displays incorporate touch sensitive technology as the method of operator control, with keyboard and mouse command capabilities to accommodate operator preferences. This system enables the balance-of-plant equipment to be routinely operated with minimal operator intervention, including the daily start-up and shutdown cycles. A configuration of the balance-of-plant DCS system is shown on Figure 2.

The next areas selected for integration were the extensive water and wastewater treatment and water quality control systems. These systems are usually supplied with self-contained programmable controller-based control systems with operator interface via local hard-wired control panels or local operator interface CRTs.

Because the Mulberry water and wastewater treatment and the water quality control systems were supplied by four different equipment suppliers, each with its own unique control system, a method to integrate the controls without adversely affecting control system costs or equipment start-up time was required.

To accomplish this, the Mulberry project team had the equipment suppliers provide their recommended programmable logic controller based control systems, standardizing on a single PLC vendor—a concept readily agreed upon by the suppliers. The operator interface functions were removed from the various water treatment equipment suppliers' scope, and a highly integrated control interface was designed by CSW personnel. The four discrete control systems were data linked and common CRT-based controls were designed to give operators a single window to control the various systems. By locating a CRT in the control room, the entire water and wastewater treatment systems could be operated by a single operator in the main control room.

A data link was also provided to the plant DCS to interface to the common alarm system and the plant historian. This innovative approach required close coordination among all parties, including CSW design and operations personnel, Black & Veatch control and chemical engineers, and each of the water and wastewater equipment designers.

The combustion turbine and steam turbine controls were also selected for integration. Both turbines have GE Mark V control systems to control both the normal operation and the safety functions of the turbines. High level control functions were added to the plant DCS to maintain the philosophy of plant integrated control. Data links were also provided to interface to the common alarm system and to fully use the DCS historical capabilities. Safety interlocks between the DCS and the Mark V were hard-wired, whereas data acquisition functions used the data links.

The final area addressed was the balance-of-plant equipment, which has self-contained control systems. This included the continuous

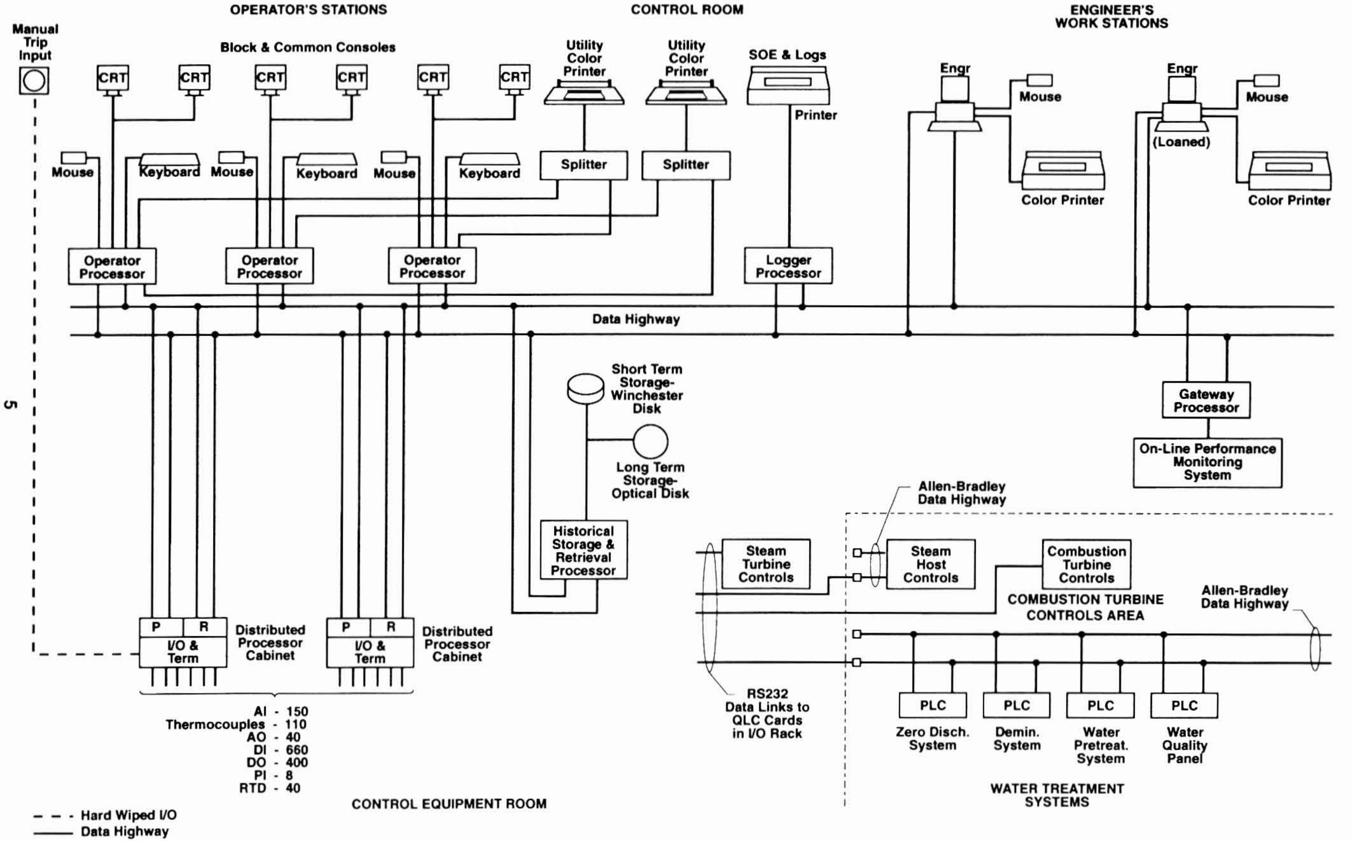

Figure 2. DCIS Configuration

emissions monitoring system, auxiliary boiler, and inlet air cooling system. Although each of these systems required minimal operator interface, control and alarming capabilities were added to the plant DCS to allow the operator to start, stop, load, and monitor these systems from the main control room.

By integrating all of these controls into a system easily understood and controlled by one operator, the Mulberry project design team took a major step in providing a plant that is easily and safely operated from a single location. This is a notable accomplishment considering the operating demands associated with a plant of this complexity.

Operating Results and Perspectives

The true measure of a plant design is the facility's subsequent performance in terms of its day-to-day operating and maintenance characteristics. Characteristics that warrant consideration include the following:

- *Daily Performance*—The cyclic operation of the plant is illustrated on the Figure 3 and 4 plots of power generation and process steam exported. Figure 5 shows the variance in plant heat rate as the ambient temperature and operating load of the facility change during the course of a day.

- *Weekly Performance*—The plant operates in a stable and predictable manner as the plots on Figure 6 illustrate, with the effects of variable temperature and humidity mirrored in the relatively small changes but still significant in terms of plant revenue, plant output, and heat rates over a 3-week period in September 1995.

- *Availability*—Unplanned outages are at a minimum as a result of preventive and routine maintenance being performed during off hours, thereby increasing the availability and reliability of the facility. The average availability factor from January 1995 to September 1995 is 97.4 percent.

- *Starting Reliability*—Trouble-free start-ups are routine, with virtually the entire process being automatic and requiring no operator intervention.

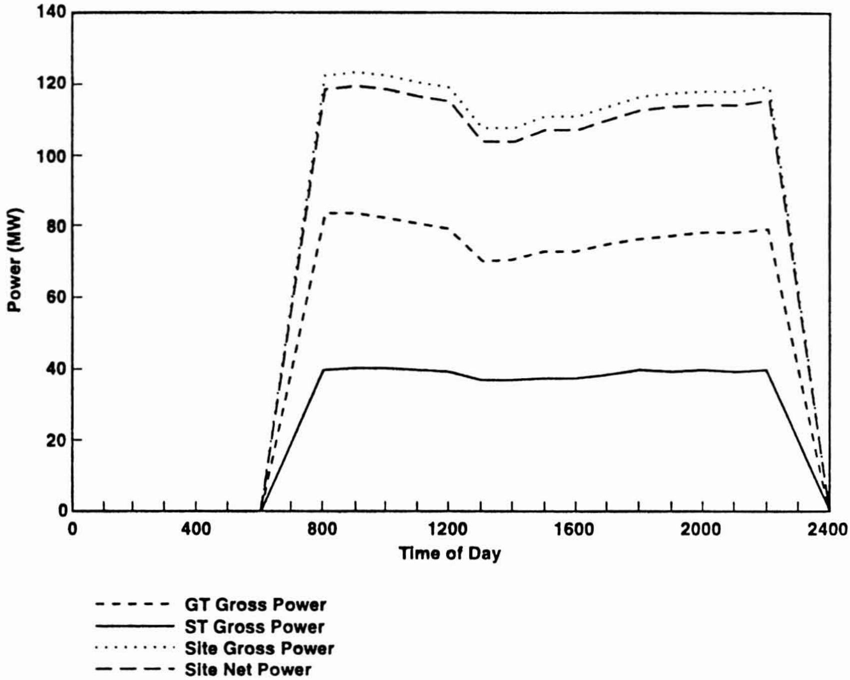

Figure 3. Mulberry Cogeneration Facility—Typical January Daily Output Power

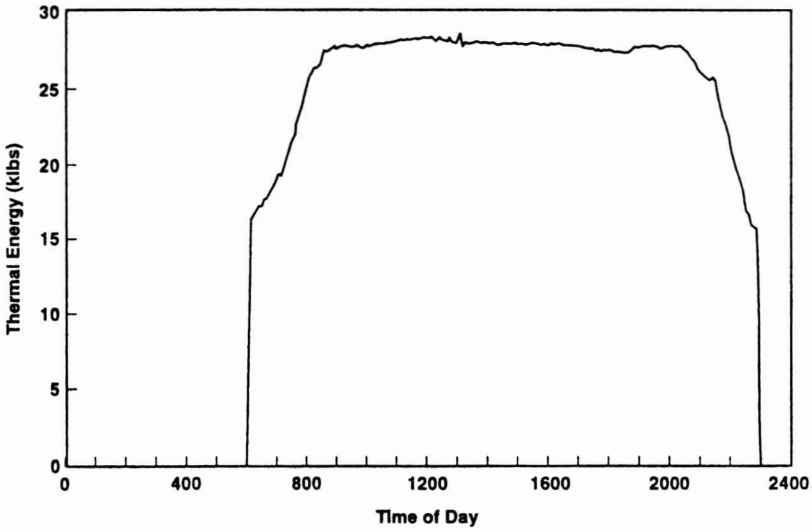

Figure 4. Mulberry Cogeneration Facility—Typical January Thermal Export

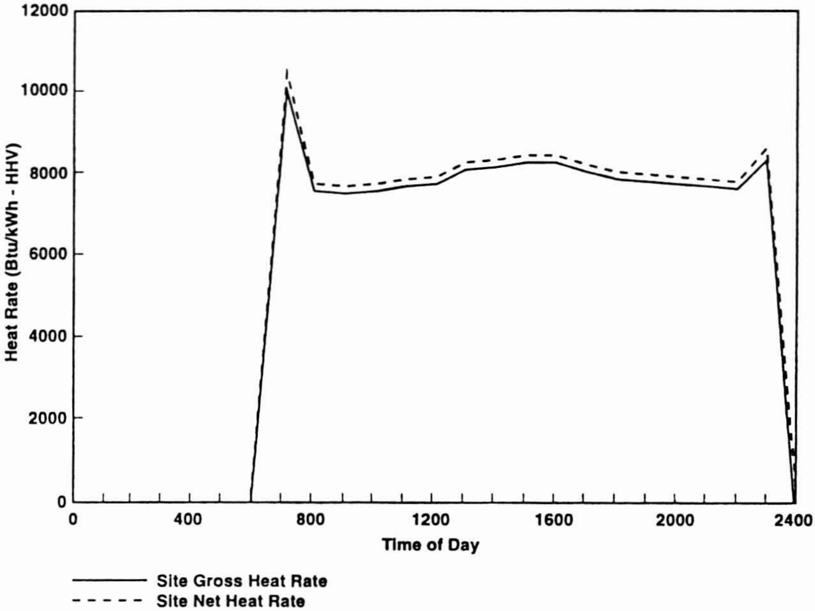

Figure 5. Mulberry Cogeneration Facility—Typical January Daily Heat Rate

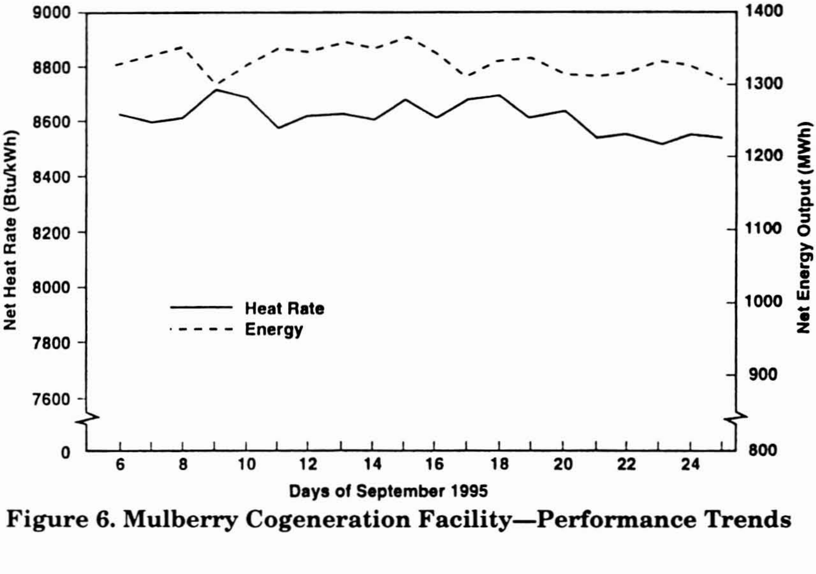

Figure 6. Mulberry Cogeneration Facility—Performance Trends

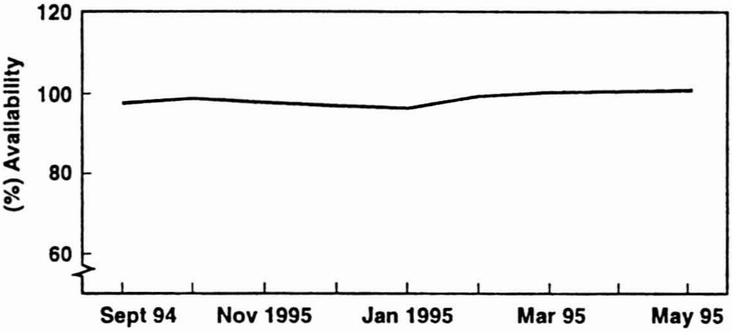

Figure 7. Mulberry Cogeneration Facility—Monthly Availability

- *Plant Staffing*—The plant is operated by two-man crews on rotating 12-hour shifts. Maintenance is performed by one mechanic and two electrical and instrument technicians, supplemented by operations personnel when required since the plant automation allows safe, reliable operation with a single operator. A utility/ warehouse person facilitates shipping, receiving, and inventory of spare parts and equipment.

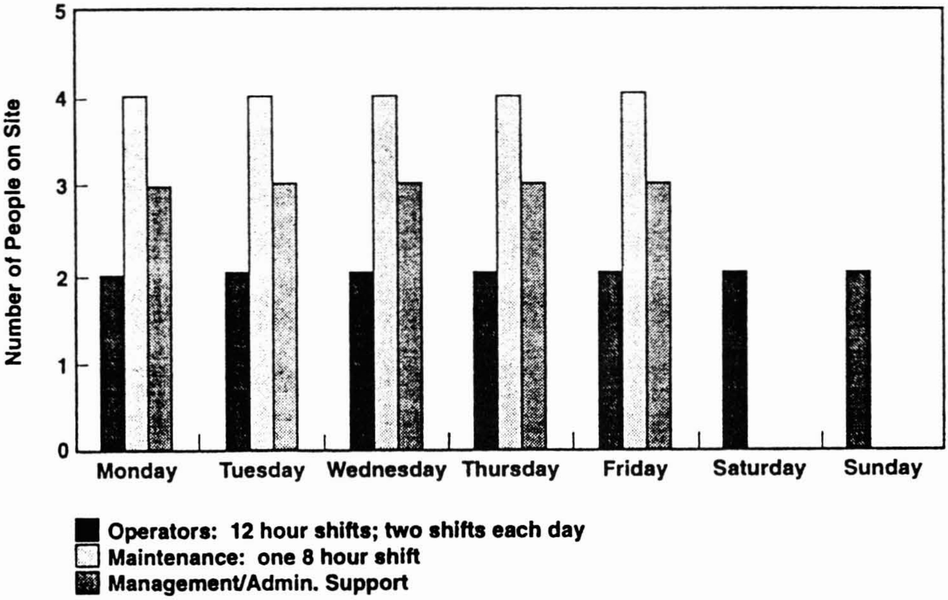

Figure 8. Mulberry Cogeneration Facility—Staffing Level

- *Zero Discharge Operations and Product Disposal*—The plant has never been shut down as a result of high wastewater inventory. A start permissive on the combustion turbine prevents start-up in the event of high wastewater inventory. Because the actual raw water characteristics differ from those originally expected, the design was slightly modified to reduce the amount of cooling tower blowdown and chemical use. The original design was for cold lime softening only at the pretreatment clarifier. With the addition of soda ash, calcium levels are reduced, increasing cooling tower cycles and reducing cooling tower blowdown. This small modification to the design allows the zero discharge system to process more wastewater than is actually produced with cooling tower blowdown. This margin allows downtime for maintenance and cleaning of equipment.

  The waste produced in the zero discharge system is nonhazardous sludge composed primarily of calcium and magnesium carbonates and sodium salts. It is disposed of in a landfill and no special permits or handling are required. Neutralized waste from the demineralizers is processed through the zero discharge system.

- *Control System*—More than 95 percent of control loops are in automatic during plant operation, with the remaining loops in manual typically due to operator preference rather than system limitations.

MEETING NEEDS ACROSS THE BOARD

The Mulberry Cogeneration Facility is in successful, reliable, and profitable service, with the complex requirements of zero discharge, extensive water treatment, process steam supply, and inlet chillers having been reduced to routine, automated operation. What was initially visualized by the developers as a straightforward combined cycle plant became much more than that as the various requirements for environmental and regulatory compliance became necessities, along with the desire to maximize output and revenues in response to growing power demands.

A delicate balance exists between a financially successful cogeneration project and the Owners' obligation to the community and the environment. As competitive pressures grow and expectations of investors, insurers, operators, and the public increase, still more creativity will be required to provide a safe, reliable, cost-effective plant on ever shorter schedules.

ABOUT THE AUTHORS

Donald C. Gray is a partner in the Black & Veatch Energy Group's Power Division, and serves as partner-in-charge on turnkey and traditional engineering design assignments. He recently directed engineering and procurement functions for Euran's 500 MW Combined Cycle Marmara Project, a globally sourced project located west of Istanbul, Turkey. BVI provided these services on a fixed-price basis with schedule and perform guarantees. He also has responsibility of BVI activities in Japan and the development of EPC projects for the emerging IPP market in that country. Clients include Nippon Steel, Chiyoda, Mitsubishi Corporation, Mitsubishi Heavy Industries and Kobe Steel.

Serving Central and South West Services, Inc., on their 120 MW combined cycle cogeneration facility located near Bartow, Florida, he managed engineering and purchasing activities for the plant which achieved commercial operation in Summer 1994. Mr. Gray also serves as partner-in-charge for several projects in Venezuela, including basic engineering on the 1,300 MW Curupao combined plant for Electricidad de Caracas and a rehabilitation study of 35 combustion turbines for CADAFE, a state-owned electric utility. In the same capacity, he is responsible for technical support of licensing for the ARK Energy/CSW Energy 150 MW combined cycle, 15,000,000 gal/year, ethanol cogeneration facility in Sacramento, California; and the technical feasibility and cost estimating services for repowering of Portland General Electric's 600 MW Beaver Station.

For the 320 MW Hardee County Combined Cycle Project which began commercial operation in 1992, he managed the Black & Veatch design, equipment supply, and start-up activities. For New England Power's 450 MW repowering of the Manchester Street Station, Mr. Gray directed turbine procurement and the development of plant detailed designs and turnkey specifications. Other assignments include feasibility studies, conceptual designs, and licensing for various clients including Duke Power, Carolina Power & Light, and Idaho Power.

For multiple TU Electric Company combustion turbine projects in the late 1980s, Mr. Gray was responsible for all engineering, procurement, and construction documents required to install 1,200 MW of generating capacity at three sites. In addition to combustion turbines, the station designs include fuel oil treatment, reverse osmosis and demineralization water treatment systems, provisions for future conversion to combined cycle, and other balance-of-plant facilities.

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