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DESIGN, CONSTRUCTION AND OPERATIONAL EXPERIENCE WITH MODULAR EQUIPMENT AT THE BEAR CANYON POWER PLANT

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ABSTRACT

The Bear Canyon 20 MW power plant was designed around numerous modular equipment packages. This modular concept resulted in significant schedule savings in design, construction, and startup. The use of modular equipment contributed to the completion of the project more than 4 months ahead of schedule.

PROJECT SUMMARY

Freeport Geothermal Resources' Bear Canyon power plant is located in the southeast section of The Geysers Known Geothermal Resource Area. The facility delivers 20 MW net to the PG&E grid under two separate Standard Offer 4 power sales agreements. Engineering for the project commenced in January 1987 with a scheduled commercial operation date of February 1, 1989. The conceptual design for the project centered around the use of modular equipment. Early project schedules, however, were based on plant design and construction using traditional non-modular power plant components. As design and construction of the project proceeded, the benefits of specifying modular equipment permitted two separate schedule compressions. The final schedule reflected a 15 percent reduction in the overall project schedule. The plant began commercial operation on October 1, 1988.

MODULAR POWER PLANT DESIGN

Engineering and design work for the project were reduced in scope and schedule by specifying modular components. The modular design concept as applied to the Bear Canyon project was to obtain equipment packages that were engineered, fabricated, and tested by the equipment suppliers. The boundaries of the packages were selected to stay within the existing expertise of the equipment suppliers.

The level of detail necessary to integrate a modular component into system design was limited to interface wiring for power and controls and external piping connections. A traditional installation requires detail wiring design and installation for all components associated with the equipment module, and design and installation of all intra-skid piping and tubing. By having the detail design of the modules performed by the equipment suppliers, the project design team could concentrate on integrating the modules into the system and plant design.

We obtained the following equipment as modular units for the Bear Canyon 20 MW Power Plant:

Turbine Generators

- Gas removal equipment
- Air compressors and accessories
- Fire water pumps and accessories
- Electrical equipment modules
- Stretford process
- Emergency diesel generator

Turbine Generators

The critical path for the Bear Canyon project schedule followed the schedule for the turbine generators. Table 1 shows the schedule durations from the preliminary and final schedules for the turbine generators. The 4-month improvement shown in Table 1 reflects the net improvement achieved for the overall project schedule.

Table 1. Turbine generator schedule durations.

Activity	Preliminary (months)	Final (months)
Specify and Procure	2.5	2.5
Review and Approve Manufacturer's Drawings	3	2
Fabricate and Deliver	11	11
Install at Site	3	1.5
Start Up	4	2.5
TOTAL	23.5	19.5

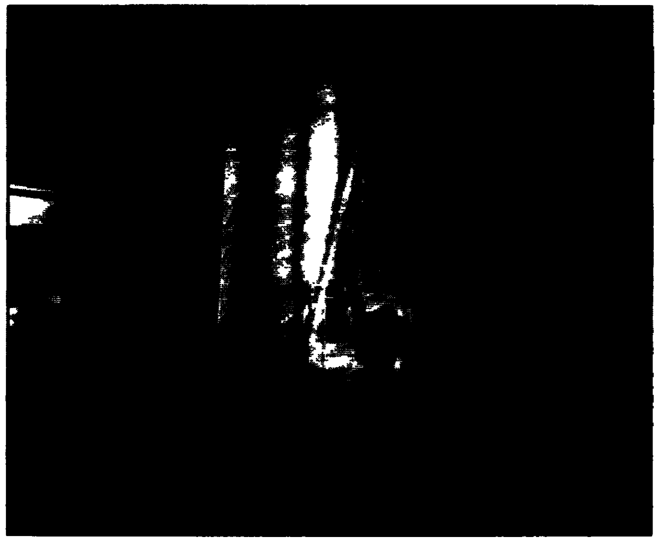

Figure 1. Modular steam turbine generator.

Each of the two Mitsubishi turbine generators was assembled in the shop and tested to the maximum extent possible. Testing included piping hydrostatic and electrical equipment tests. Functional testing at the factory was not performed. The turbine generator lubricating oil system was included on the skid and was flushed at the factory. Only a brief finish flush was required at the site.

Substantial planning was required to arrange transport of the turbine-generators to the site because of their size and weight. Each turbine generator module was 34 feet long, 12 feet wide, 12 feet high, and weighed 96 tons. The modular turbine generator is shown in Figure 1.

Gas Removal Equipment

The gas removal equipment was designed and fabricated by Nash-Kinema, Inc. Four separate skid mounted packages were provided for each unit. Each skid included three steam jet ejector elements, a shell and tube condenser, and interconnecting piping between the ejectors and the condenser. The ejector and condenser packages greatly reduced the number of interface points for the system designers. As a result of accelerated order placement and drawing approval, the manufacturer was able to ship the equipment approximately 2 months ahead of schedule.

Air Compressors and Accessories

Two identical air compressor packages were designed and fabricated by Ingersoll-Rand. Each package included an air compressor and motor, after cooler, air dryer, air filters, and air receiver. The units were assembled, wired, and test run in the manufacturer's shop. The air compressor skids are shown in Figure 2.

Figure 2. Air compressors and accessories.

Fire Water Pumps and Accessories

The plant fire pumps were provided by Allis-Chalmers. The standard unit included a diesel-driven fire pump with controller, motor-driven fire pump with controller, pressure maintenance pump with controller, and various accessories. The fire pump module is shown resting on its foundation in Figure 3.

Electrical Equipment Modules

Five prefabricated electrical equipment modules were provided for the switchgear. Three modules were provided by Brown Boveri Corp. for plant auxiliary equipment and two were provided by Mitsubishi for turbine generator electrical equipment. Each module was assembled, wired, and tested in the manufacturer's shop. Each

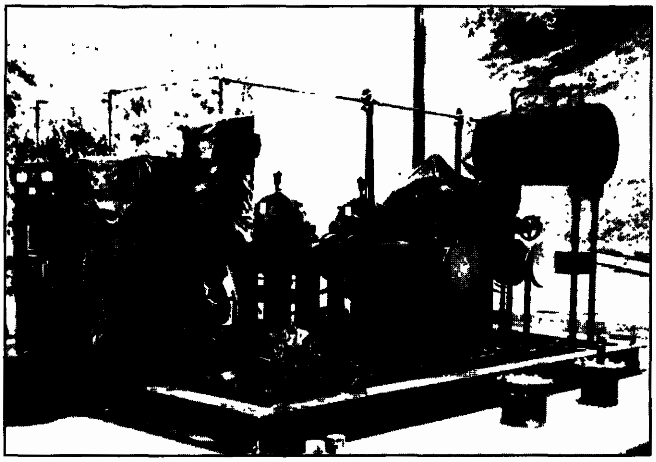

Figure 3. Fire water pumps and accessories.

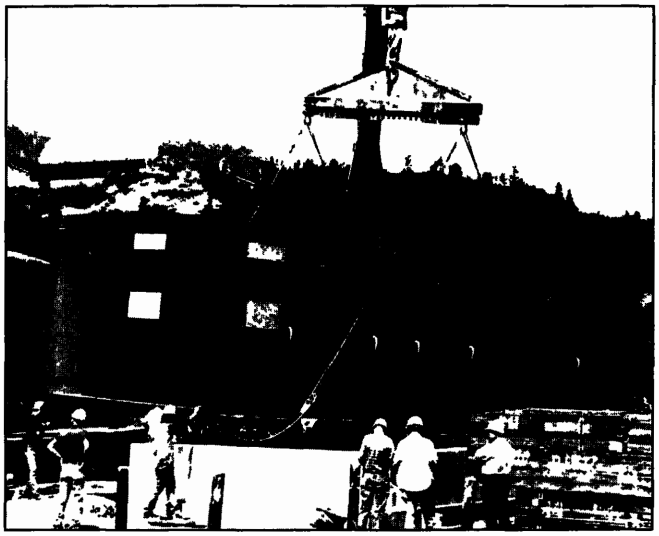

Figure 4. Electrical equipment module.

module sits on its own foundation and has its own climate control system and halon fire protection system. An electrical equipment module is shown being installed on its foundation in Figure 4.

Stretford Process

The Stretford process was designed, fabricated, and erected by the Peabody Process Systems Division of Flakt, Inc. The equipment was assembled into modules in the shop. The modules included foundation steel, pumps, tanks, interconnecting piping, and wiring. These modules were then shipped to the site for final assembly.

Emergency Diesel Generator

A complete skid mounted emergency diesel generator was furnished by Caterpillar. All accessories were mounted on the skid in the manufacturer's shop. The diesel generator was test run in the shop prior to shipment. The diesel generator is shown in Figure 5.

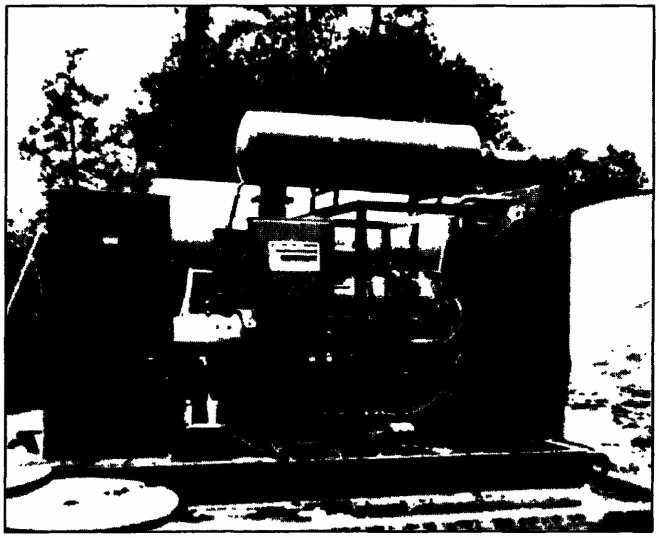

Figure 5. Emergency turbine generator.

Summary

By selecting the modular components as described earlier, the schedule for the overall design effort was shortened by at least 1 month. Schedule compression was achieved by reducing the detail interface information required from the equipment suppliers to complete the system design.

PLANT CONSTRUCTION USING MODULAR COMPONENTS

Modular and packaged components reduce the time and labor necessary to complete construction of the power plant. Savings are realized through greater use of shop labor and a reduction in the need for skilled trades at the job site.

The larger and heavier equipment modules, however, required lifting equipment of greater capacity than would otherwise be necessary. Installation of each module included placing the skids on their foundations, installing anchor bolts, leveling, and grouting.

Installation

The turbine generators at Bear Canyon were lowered onto their foundations using jacks. All other equipment modules were installed using a crane. The weight of the lifts was greater for modular components, but the number of lifts was far fewer than would be the case for a conventional design.

Following installation of the modules, skilled labor was required only to check and make minor adjustments to factory alignments. Electrical work was limited to power and control terminations at skid interface points. Mechanical work was limited to completing piping connections at the skid boundaries. Additional schedule compression was achieved as a result of having all intra-component wiring and piping completed in the shop. Table 1 shows that the site installation schedule for the turbine-generator was reduced by 1-1/2 months. The other modular components were also installed in less time than was scheduled. For example, approximately 2 weeks were saved in the electrical construction effort as a result of having the electrical switchgear installed and wired in the electrical modules by the manufacturer.

Summary

Additional planning is required to realize the maximum benefit from modular components. Adequate equipment must be available to lift the heavier modular components. Modular components can be quite large, resulting in potential site access problems. Finally, transport of large loads requires permits and, once on the road, travel is slow. However, even with these constraints, the use of modular equipment reduced the construction schedule by 1-1/2 months.

PLANT STARTUP WITH MODULAR COMPONENTS

Shop assembly of equipment packages permitted shop testing of components that would have otherwise required testing and debugging at the jobsite. For equipment modules that were subjected to full functional testing in the shop, startup activities were reduced to verification of the interface wiring and piping and confirmation of satisfactory operation. Other modular components required more extensive checkouts and verifications, but the probability of significant delays in completing the startup work was greatly reduced for the modular components. The net result was a compression of the startup schedule along with a greater level of confidence in the schedule during plant startup.

Startup

Startup of the turbine generators included a 1-week oil flush, checkout and adjustment of the electro-hydraulic control system, testing of the piping and wiring that interfaced with the module, and functional testing of turbine auxiliary equipment. The time required to accomplish these tasks was 1-1/2 months less than the time anticipated for a non-modular turbine generator.

The air compressor modules and the emergency diesel generator module were functionally tested in the manufacturer's shop. The other equipment modules required functional testing prior to being placed in operation.

Summary

Startup of modular equipment requires less time at the job site than non-modular components. Equipment that has been functionally tested in the manufacturer's shop requires the least amount of startup time at the site. The startup schedule for the Bear Canyon Project was shortened by 1-1/2 months by using modular equipment.

PLANT OPERATION WITH MODULAR COMPONENTS

The Bear Canyon 20 MW power plant has been in commercial operation for more than 20 months. During this period, the plant has been operating at a 93 percent capacity factor. From this performance record it is apparent that the modular equipment is performing well. Teething problems did occur with some equipment during early operation, but the problems could not be directly attributed to the modular concept.

The turbine generator manufacturer was called on to repair a steam leak at the casing horizontal joint and to resolve hardware interface problems in the control system. Problems with the 2.4 kilovolt (kV) switchgear in one of the electrical equipment modules were repaired by the manufacturer. Overheating of the air compressors during early operation was traced to fouling from the open cooling water system. Installation of a closed loop, water to air cooling water for the air compressors corrected the problem.

Summary

From an operational history of almost 2 years, the performance of the modular equipment has been at least equal to the performance of similarly sized, traditional power plant equipment. The plant is currently operating at a capacity factor above the design goal for the project. In the plant's infancy, equipment problems in the modular components occurred most frequently in those components that were not subjected to functional testing at the factory. A reduction of early operational problems with modular components may be achieved by greater involvement of the system designer in the preproduction detail drawing review process for the modular components.

ECONOMICS OF MODULAR CONSTRUCTION

The use of modular equipment resulted in cost savings in construction and startup of the power plant. However, the primary economic benefit from the application of modular construction was the early completion of the project.

Design

Most of the equipment packages obtained for the Bear Canyon power plant were engineered specifically for this project. Engineering for these modules was performed entirely by the equipment manufacturer, rather than being shared between the manufacturer and the system designer, as is the case for design work using conventional components. Only the fire pump package and the emergency diesel generator were provided as standard modules for which the supplier had to do little or no engineering. As a result, cost savings for the overall engineering and design effort were insignificant.

Construction and Startup

Construction and startup of the power plant was completed in approximately 20 percent less time than was originally scheduled for the project using conventional components. This reduction of time and labor along with the need for less skilled labor resulted in a cost savings of approximately $1.1 million for the $31 million project.

Summary

There are significant economic benefits from using modular construction. Engineering and design costs are reduced when standard, pre-engineered modules are used. The reduction of time and labor required to construct and start up the Bear Canyon power plant saved more than 3 percent of total project costs. Finally, early completion of the project resulted in an early start of revenue from power sales.

CONCLUSIONS

Schedule compression is available at all phases of a project by using modular equipment. Detail design of component packages is performed by the equipment suppliers who are intimately knowledgeable about the requirements for their equipment. The project design team, therefore, can concentrate on integrating the equipment package into the system and plant design. The construction effort is greatly simplified as a result of having electrical and piping details completed in the shop. Likewise, testing and startup activities are also simplified for modular equipment. Equipment modules that have been functionally tested in the shop provide the greatest schedule improvement with a high confidence level in their performance.

The use of modular components requires additional planning for the construction effort. The larger sizes and greater weights of the equipment modules require long lead planning for transport to the jobsite. Permits must be obtained early and the schedule must allow for longer transport times. In addition, lifting and handling the equipment modules may require larger and more specialized equipment.

The costs to design, construct, and start up a geothermal power plant are reduced through the use of modular equipment. Savings for the Bear Canyon power plant exceeded 3 percent of the project costs.

Although the modular concept is not new, previous applications have been limited to small projects. On the Bear Canyon project, we successfully applied the concept to a mid-size geothermal steam power plant. The modular concept was a major factor in the elimination of 4months from a 23 month design and construction schedule. Early completion of the project resulted in an early start of revenue from power sales.