A Student Designed Instructional Cogeneration Laboratory

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Abstract

The Mechanical Engineering Department at California State University, Sacramento (CSUS) has received a $220,000 grant from the National Science Foundation, the Sacramento Municipal Utility District, Pacific Gas and Electric, and the CSUS to replace the aging steam power plant in its Energy Systems laboratory with an updated cogeneration system. Three teams of students have worked on this project for the last three semesters from the initial design state to the selection of components. This paper describes this special student project from initial design to the selection of the 75 kW gas turbine generator connected to an electrical load bank, the waste heat boiler, four heat exchangers, the absorption chiller, the existing cooling tower, and the computer based data acquisition system.

Introduction

Cogeneration has gained world wide importance for small scale energy production. Following this trend, in 1993 the Mechanical Engineering Department at California State University, Sacramento (CSUS), undertook the design and construction of a cogeneration laboratory. The purpose of this scaled-down cogeneration plant is to allow students to conduct experiments using current technology in conjunction with the study of thermodynamics systems. This project has provided an excellent learning environment for Mechanical Engineering and Mechanical Engineering Technology students in their senior project classes; much of the design was completed by the students. By designing an operating cogeneration plant the students encountered "real world engineering problems, learned about several individua1 components and calculated how the integrated system would perform.

Student Design of the Cogeneration Plant

The design and construction of a senior project is required of all students in the Mechanical Engineering and Mechanical Engineering Technology programs at CSUS. The first semester is &voted to the design of the project and the second semester to its construction and testing. In the case of the cogeneration laboratory the procedure was modified to have the students work on the design as a continuing project. Design teams of six to eight students have worked on the project for three semesters and one summer starting in the fall of 1993.

While the proposal to NSF outlined a design including a gas turbine, a boiler, heat exchangers, an absorption cooler and air handler, with tentative sizes, there were many variations to be studied. During the first semester 18 students worked on developing alternative &signs of the system. A key question was the selection of turbine size and fuel as described below. As the project progressed other question, some minor and some significant, arose. For example, the use of the electricity generated was extensively studied by one group of students. One member of this group has considerable experience with an electrical utility and was a key player in designing an interconnection to the campus electric grid. The other option was to simply dissipate the energy as heat in the load bank Ease of changing the load and fears (probably unfounded) about causing surges on the campus electrical system led to using the load bank option.

The prior experience of students proved very helpful when it came to developing a final design with vents, surge tanks, drain valves, etc. While being aware of a need to include such items this is clearly an area where the faculty investigators had limited practical experience.

Turbine-Generator

Originally, a 75 KW turbine-generator (T/G) was considered. This unit was considered to be big enough for educational purposes and relatively inexpensive.

However, when many T/G manufacturers were checked none of them could supply such a small unit. To the best of the design team's knowledge, Alturdyne is the only company that sells and warrants small gas fired turbines capable of meeting our needs. Alturdyne offers a refurbished 150 horsepower gas turbine powerplant coupled to a 75 KW generator set for approximately $50,000, depending on instrumentation requirements.

Boiler

Waste heat is defined as the heat which is generated during a thermodynamic process or cycle which can not be recovered or utilized during the process and is rejected to the environment. For internal combustion engines and gas turbines the majority of the available energy in the fuel is lost in the form of heat, either in the exhaust or by radiation to the surrounding environment. The recovery of this heat energy and subsequent application to some useful purpose is the aim of cogeneration. The ultimate goal is to maximize the overall thermodynamic efficiency of the system which reds in energy cost savings. The criteria for selecting a boiler normally depends on the desired steam output. Manufacturers of waste heat recovery units were asked to size an appropriate boiler for the available heat source. The three responses were received from Beaird Industries, Clayton Industries and Enercorp. A vertical, two drum boiler designed and built by Enercorp was finally chosen as being the most suitable for our needs. This unit produces 533 Kg (1175 lbs/hr)of steam per hour (dry saturated steam) at 0.27 MPa absolute (39 PSIA).

Cooler/Condenser

The steam is condensed in tWO shell and tube heat exchangers; i. e. condensers. The first condenser produces hot water at **93 &g C (200 deg** F) to operate an absorption chiller. The second condenser condenses the remaining steam with the heat being rejected to the existing cooling tower.

The machinery that will be installed in the power laboratory at **CSUS** is limited in size because of the nature of its subsequent use. Although the system will obviously be able to produce power and provide air cooling, its primary function will be as a demonstration tool and teaching aid. The size of the chiller to be installed was the smallest commercially available unit with a cooling capacity of 10 tons, or 35 kW (120,000 Btu/hr). There are two main types of absorption chilling, single stage and double stage. For this small system a single stage provides satisfactory performance and is more economically feasible.

The chiller manufactured by Yazaki will be excellent for this instructional application. The operating parameters of the Yazaki WCF- 10 chiller are very flexible. Although the nominal cooling capacity is 10 tons, the capacity and the coefficient of performance can vary greatly. Obviously this flexibility will prove beneficial and will be a useful tool in the laboratory setting.

Cooling Tower

A necessary component for the operation of the condensers and the absorption chiller is the cooling tower which presently exists behind the power lab building. The tower is quite old and the manufacturer, Marley Corporation, had very little information available concerning its capacity. Typically the cooling tower has inlet and outlet temperatures of 35 deg C (95 deg F) and 29 deg C (85 deg F), respectively. These match the temperatures required by the condensers and the absorption chiller. At 1075 liters per minute (278 gallons per minute) the tower can dissipate 407 kW (1.39 million Btu/hr).

Stack

The exhaust from the boiler will be routed through a stack and discharged outside at a location on the roof. While originally planning to use the existing stack, it became obvious that a new stack would be required. A close examination of the stack requirements led to detailed research on this component. Routing the stack to an appropriate location will be of prime importance to minimize turbine noise. If the noise exceeds the level stated in acoustic regulations a silencer will be necessary. The turbine emissions will be monitored by a special NOX meter to insure compliance with the regulation set forth by the EPA (Environmental Protection Agency) and the county of Sacramento.

Cogeneration Design Layout

Considerations in the design layout for the cogeneration project required knowledge of the available space, size of each individual component and associated equipment, and the requirements that each piece has with reference to the entire system being installed. Other considerations included, but were not limited to, the constraints placed on the system due to compliance with existing building codes-and the existing structure itself. The Energy Systems Laboratory is a roughl y square room approximately 60 by 60 feet with a ceiling height of approximately 15 feet. The steam laboratory equipment which is being replaced occupied the northern end of the room in a space roughly 7 feet by 40 feet. Final approval for the design layout must be verified by a number of people, including the campus architect, state fire marshall, and project manager. For this project several design schematics were proposed with the merits of each having to be weighed before approval of one design. Once the &sign was chosen, a final layout was drawn from which equipment placement, routing of piping and electrical conduit, and pump selection could be made.

Instrumentation

Computer (PC) based instrumentation was chosen for this cogeneration project. That is to say, information or input from each of the instruments will be collected and displayed solely on a computer. An alternative to this would be to physically display each instrument at its respective location or have a combination of both styles. (Some of the components have limited instrumentation to provide safe operation.) These instruments, namely, pressure transducers, temperature sensors, flowmeter, hygrometer, volume gauges, turbine rpm gauge, and NOX metering devices are to be routed through twisted pair wires to expansion modules located at the personal computer. Information collected at the expansion modules is amplified and sent to two interface boards located inside the personal computer. The interface board serves to interpret the data received by the expansion modules and correctly format it for display on the computer screen. The data received on a "real-time" basis are interpreted by appropriate software. The software chosen, Labtech, has numerous features which are advantageous to this project.

Final System Description

During the second semester and the last summer the student design team made final selection of the components and completed the design of the cogeneration plant. A schematic diagram of the facility is shown in Figure 1.

The primary component is Alturdyne's 75 kW gas turbine generator which is a refurbished 200 kW (150 HP) Solar "Titan" unit coupled to a 75 kW generator. The original plan was to use kerosene fuel; the discovery--by the studenta- of a high pressure gas main immediately adjacent to the building led to the decision to fire the unit with natural gas.

The electrical energy generated is dissipated in a resistance load bank which will be located on the roof of the laboratory. The load bank has eighteen 5 kW resistors which can be switched on and off individually. Connecting the electrical output to the campus electrical system was considered and found to be impractical.

The Yazaki absorption chiller uses water as a working fluid and lithium-bromide as a carrier. This unit produces 5900 kg/hr (13,200 lbs/hr) of chilled water at 8 &g C (46 deg F). Heat rejected from the chiller is dissipated in the cooling tower.

The system design includes a PC based data acquisition system which monitors all major pressures, temperatures and flows. In the gas turbine the compressor inlet and discharge pressures and temperatures are measured; also, the turbine inlet temperature is monitored. Stack emissions will be continuously monitored with particular attention to NOX levels.

The total cust of the system is approximately $250,000.

Use of The Cogeneration Plant

The system will be used in engineering measurements courses in both the ME and MET programs. These courses are scheduled in parallel with the second thermodynamics lecture course in each program. Thus the students will be given both theoretical and laboratory instruction on both the Brayton gas turbine cycle and the absorption refrigeration cycle. Experiments will typically include the calculation of theoretical cycle operating conditions and efficiencies, comparison of them to experimental results and the &termination of component efficiencies. The experimental work will also provide experience with modem data acquisition, an important component of present day engineering education.

A typical first experiment would be operating the gas turbine over a range of loads from perhaps 50 to 75 kW with the boiler simply being a way to cool the exhaust gases and all steam being condensed. A second experiment would vary the operation of the boiler. Varying the operation of the chiller would be the main objective of another experiment. Finally, the operation of the entire system and a detailed analysis will provide a valuable lesson on cogeneration.

Another use of the facility will be the training of operating personnel. One of the project sponsors, the Sacramento Municipal Utility District (SMUD), has one cogeneration plant in operation, in the Sacramento area.

Two more plants are under construction and a fourth is planned These plants will have a total capacity of about 550 MW (SMUD 1995). The operation of these plants will be done by independent contractors; thus SMUD is very interested in having personnel gain experience in the CSUS cogeneration laboratory.

Future plans include developing experimental work on two phase heat transfer using the fan coil, boiler and condensers as well as other experimentation with the cogeneration system itself.

Having the students do much of the design bad several advantages. First, it provided the students with valuable experience which they wouldn't otherwise get. Secondly, it relieved the faculty of many of the routine tasks--e.g. finding suppliers--which go with such a large project. Not so obvious is the fact that involving students in the design made them partners in a major undertaking of the department; it expressed confidence in their abilities. Lastly, in some area, such as connecting the generator to the campus electrical grid, it provided expertise which didn't exist in the faculty. 130th the faculty and the studenta feel the design process was a positive experience.

Acknowledgement:

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References:

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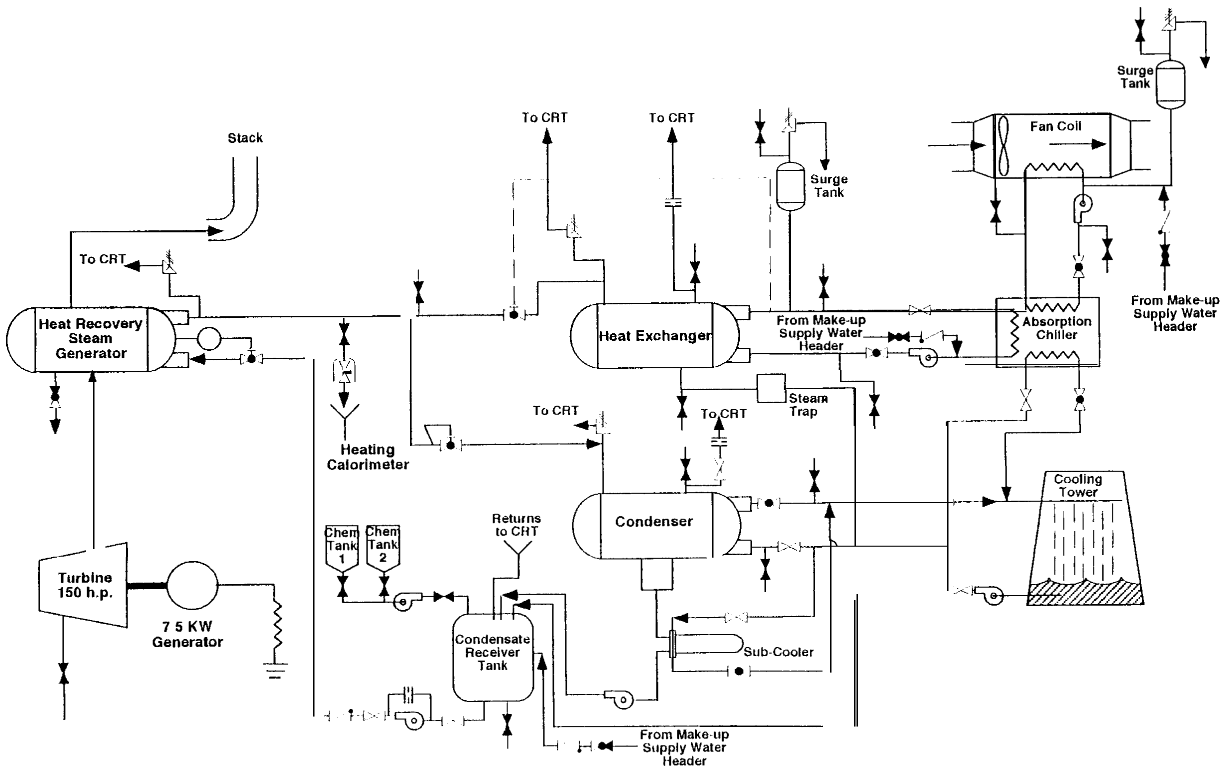

Figure 1. Schematic Diagram of the Co-Generation Laboratory