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An Introduction to Power Plant Cogeneration

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1. DEFINITION. Cogeneration is the simultaneous generation of electricity (or mechanical energy) and steam (or other thermal energy such as hot air or hot water) from the same fuel (or energy) source.

2. CYCLES. Cogeneration cycles consist of energy conversion equipment such as boilers, turbines, and electric generators arranged to produce both electricity and steam or other thermal energy.

2.1 BASIC CYCLE. The basic conventional cycle consists of a steam boiler and turbine, which drives either an electrical generator or other mechanical equipment, and from which steam is extracted or exhausted to environmental heating or processes.

2.2 COMBINED CYCLE. See Figure 1 for a typical cogeneration cycle. The combined cycle consists of a gas turbine which exhausts to a heat recovery steam generator (HRSG). The HRSG in turn produces steam to drive a steam turbine. Both turbines can drive a single or separate electrical generator. Low pressure turbine exhaust steam can be used directly for process or heating purposes or the steam can be otherwise condensed and returned to the HRSG.

3. EFFICIENCY. The overall efficiency of a cogeneration cycle is a ratio of all usable energy (electricity, steam, hot water, etc.) obtained from the cycle to the energy (fuel, solar, etc.) input to the cycle.

4. METHODS OF OPERATION

4.1 PARALLEL OPERATION. Under parallel operation, the cogeneration plant is electrically interconnected and synchronized with an electric utility distribution or transmission system, with both the cogenerator and electric utility generating electricity simultaneously. Under parallel operation, some electricity will be flowing either to or from the cogeneration system.

4.1.1 REASONS FOR PARALLELING

4.1.1.1 SELECTIVE USE OF ELECTRICAL ENERGY from the electric utility by the cogenerator. The cogenerator purchases electrical energy during periods and in amounts as needed to supplement its cogeneration capabilities.

4.1.1.2 SALE OF EXCESS ELECTRICITY by the cogenerator to the electric utility. The cogenerator has a large heat demand for process use or environmental heating and can cogenerate electricity in excess of facility needs. The excess electricity generated is sold to the electric utility generally at a rate which is less than the generating costs; this is usually not economical.

4.1.1.3 PEAK SHAVING. Cogeneration is used to minimize demand charges from the electrical utility.

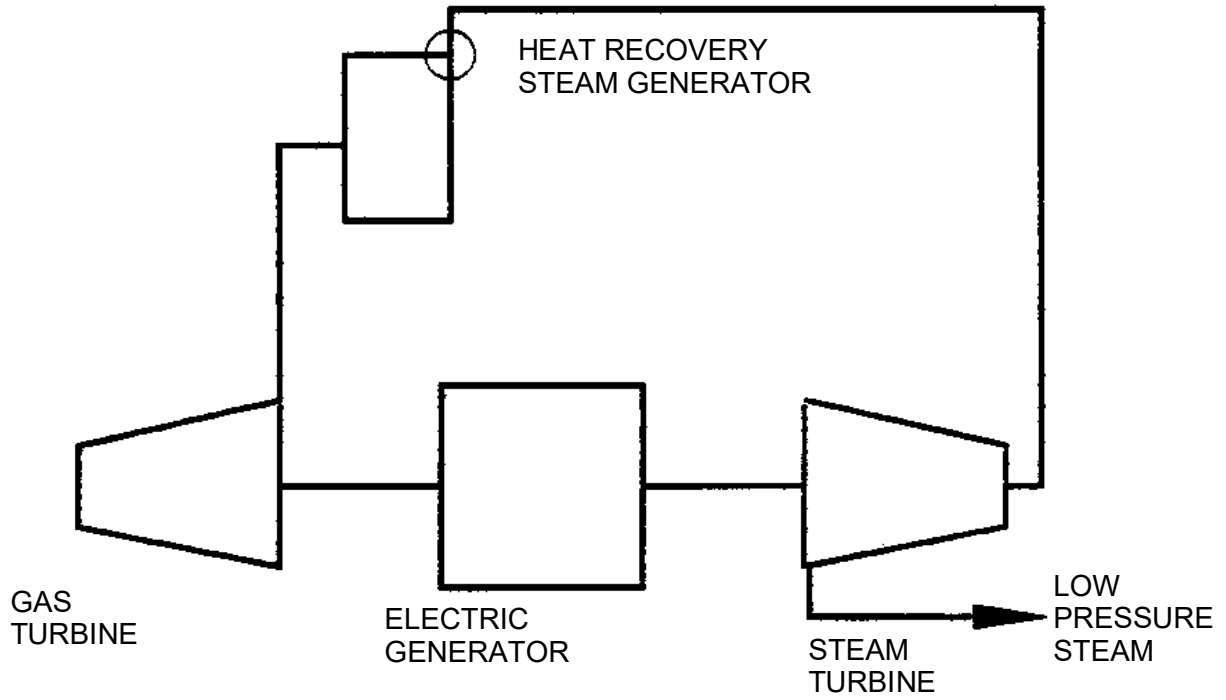


Figure 1
Combined cycle

4.2 ISOLATED OPERATION. Under isolated operation, the cogeneration plant generates, independently of the electric utility, all electricity and steam needed and used by the facilities that it serves.

4.2.1 REASONS FOR ISOLATION

- The facilities and cogeneration plant are in a remote location and electricity is not or cannot feasibly be made available from an electric utility to the facilities.
- Critical mission requires self-contained system, including onsite standby.
- Facility heat and electrical needs coincide to permit self-contained (total energy) cogeneration system.
- Agreement for parallel operation cannot be reached with electric utility.

4.2.2 ELECTRIC UTILITY CROSSTIE. A cogenerator may operate in isolation and may also be interconnected to an electric utility for service during maintenance down times and/or for standby service for use during an emergency outage of the cogeneration plant. If a cogenerator is not crosstied to an electric utility, backstart capability must be provided.

4.3 BASE LOAD THERMAL. In this mode of operation, the cogeneration equipment is sized and installed to generate electricity at a constant (base) load equal to that afforded by minimum steam demand, as determined from periodic swings in steam load. Supplemental electrical demands above the base load would be supplied by the electric utility through a parallel arrangement. Supplemental steam demands would be supplied by the use of supplementary firing of heat recovery steam generators or separate boilers.

4.4 BASE LOAD ELECTRIC. In this mode of operation, the cogeneration equipment is sized and installed to generate electricity at a constant (base) load equal to the minimum annual (or some other chosen period) electrical demand. Some of the electricity included in the base load may not be cogenerated but may serve to reduce demand supplied by an electric utility. Because of the duality of steam production and utilization, automatic extraction condensing turbine generators lend themselves to base load electric operation.

4.5 ELECTRIC PEAK SHAVING. Peak shaving is accomplished by the use of onsite generation or cogeneration equipment to limit the demand, during peak electrical use periods, of electricity purchased from an electric utility through a parallel arrangement. Peak shaving is usually done on a daily cyclic basis. The objective of peak shaving is to economically reduce electric utility demand charges and overall electrical energy costs. If there is a high demand for steam during peak electric demand periods, cogeneration can be used to supplement purchased power to achieve peak shaving, if it proves to be economical.

4.6 ELECTRIC AND THERMAL TRACKING

4.6.1 ELECTRIC TRACKING. Electric tracking is defined as the continuous generation of electricity to meet the electrical demands of a facility as they occur throughout the daily load swings. With electric tracking, cogeneration equipment is used to generate as much steam as the electric load will allow with supplemental steam demands generated directly

by use of boilers. The use of automatic extraction condensing turbine generators and combined cycles also provides the means for electric tracking.

4.6.2 THERMAL TRACKING. Thermal tracking is defined as the continuous generation of heat or steam to meet the thermal demands of a facility as they occur throughout the daily load swings. With thermal tracking, cogeneration equipment is used to generate as much electricity as the steam load will allow with supplemental electrical demands generated on other equipment such as gas turbine generators, diesel generators, and steam turbine generators. Automatic extraction condensing turbine generators and combined cycles provide the means for simultaneous tracking of both electric and thermal loads.

5. INTERCONNECTION WITH UTILITY

5.1 OPERATION REQUIREMENTS. Operational requirements of a cogeneration plant interconnected with an electric utility are conditions of either the electric utility rate schedule for parallel generation contract service or separate contract of agreement between the cogenerator and utility. The conditions as set out in the contract may be site specific and cogeneration system specific. Typical examples are as follows:

- Voltage, frequency, and wave shape of alternating current to be delivered to the utility system shall be maintained within specified limits.
- The utility may reserve the right to limit the amount of electrical load delivered to the utility system at certain times and as utility electric operating conditions warrant.
- The utility may reserve the right to inspection, observation of testing, and specification of certain maintenance requirements.
- The cogenerator may be required to notify the utility prior to initial energizing and startup testing of the cogeneration facility.
- The cogenerator may be required to notify the company prior to each start of energy delivery and interconnection to the utility system.
- The utility may require that the cogeneration plant's scheduled outage for maintenance coincide with periods when utility power system demand is low.
- The utility may require a demonstration of reasonable reliability of the cogeneration plant over the life of the contract.

- The utility may require a contract specifying technical and operating aspects of parallel generation.

5.2 INTERCONNECTION EQUIPMENT

5.2.1 UTILITY STANDBY SERVICE. This arrangement requires a manual or automatic throwover switch that will first disconnect the cogeneration electrical source from the facility electrical load before connecting the facility electrical load to the electric utility service entrance line.

5.2.2 PARALLEL OPERATION. This arrangement requires two manually operated disconnect switches, one to disconnect or connect the cogeneration electrical source to the facility electrical load and the other to disconnect or connect the facility electrical load to the utility service entrance line. In addition to these switches, meters for billing will be required and are usually supplied, owned, and maintained by the electric utility. The manual switch for connect or disconnect of the utility service from the facility electric load and cogeneration system electric source is usually a mandatory contract requirement by the utility. The utility will further require that this switch be under exclusive control of the utility, and that it must have the capability of being locked out by utility personnel to isolate the utility's facilities in the event of an electrical outage on transmission and distribution facilities serving the cogenerator. The other manual switch or isolation device will also usually be required by the utility contract to serve as a means of isolation for the cogeneration equipment during maintenance activities, routine outages, or emergencies.

The interconnection with the utility for parallel operation also requires synchronizing controls for electrically synchronizing the cogeneration system with the electrical utility system.

5.3 LINE AND EQUIPMENT PROTECTION. Parallel operation introduces variables in distribution line protection in that fuses and other sectionalizing devices may be affected by generator contributions to fault currents. Line sectionalizing studies should be made to verify correct operation of sectionalizing devices over the range of conditions that could arise. Generators operating in parallel with the utility system need protection against overload. To protect both line and cogeneration equipment in the event of unacceptable fault, one protective relaying system is required to separate the utility system from the cogeneration bus and another protective relaying system is required to separate the cogenerator from the cogeneration bus. The required protective relay functions are usually designated by the electric utility and the final design of the complete protective relaying system must have the approval of the electric utility prior to initial operation of the cogeneration system.

5.4 UTILITY POWER RATES. Utility power rates are based on the utility's costs to provide both electrical capacity and energy. This is reflected in the billing as charges for electrical demand and energy.

5.4.1 DEMAND CHARGE. The electrical demand for billing purposes is usually determined from demand instruments located at the customer facility such as a kW meter

and associated printing recorder which periodically records the kW load or demand. In some cases, the demand may be determined by tests made by the utility. Billing demand is usually established on a monthly basis and is taken as the highest demand recorded, usually in any 30-minute interval. Many utilities' rate schedules also contain a ratcheted demand clause which establishes a minimum billing demand based on the highest, or some percentage of the highest, demand occurring in the previous 12 months, or some other chosen period. The effect of the ratchet may result in a billing demand for a month of low demand, for instance a winter month, that is based on a high demand in a previous summer month. Rate schedules take various forms, depending on the utility and state public utility commission practices. Rate schedules for demand will vary according to geographic area and usage.

5.4.2 ENERGY CHARGE. The energy usage for billing purposes is determined from kWh meters located at the customer's facility. Energy charges are usually tied to billing demand in such a manner that low energy use at a high demand is charged at a high rate whereas a large energy use at a low demand is charged at a lower rate. Therefore any peak shaving scheme which can be used to reduce demand can result in savings which may economically justify the investment costs for peak shaving equipment and its fuel usage, operation, and maintenance. Rate schedules for energy will vary according to geographic area and usage.

5.4.3 TOTAL ELECTRIC BILLING. The electric billing by the electric utility is usually computed and issued on a monthly basis. The total electric bill will usually be the sum of

the demand and energy charges plus adjustment for such items as fuel cost, research and development surcharge, and taxes.

5.4.4 OTHER FACTORS FOR SALE OF ELECTRICITY. The rates charged for electrical demand and energy depend on other factors or the type of service. These are typically as follows:

- Service at secondary voltage.
- Service at primary voltage (12,000 to 69,000 volts).
- Standby service.
- Breakdown service.
- Supplementary service.
- Seasonal service.
- Water heating.
- Space heating.

5.4.5 PURCHASE OF ELECTRICITY. For parallel operation with a cogenerator, electric utilities under certain terms and conditions, may purchase excess electricity generated by the cogenerator. As covered under section 201 of the Public Utility Regulatory Policy Act of 1978 (PURPA), cogeneration facilities that are not owned by an electric utility and that meet certain standards are eligible for special incentive rates to be paid to them by the utility as required under Section 210 of PURPA. These incentive rates that the utility is obligated to pay to qualifying facilities are not required directly by PURPA but are required by rules promulgated by the Federal Energy Regulatory Commission (FERC.) These

rules by FERC provide that electric utilities must purchase electric energy and capacity made available to the electric utilities by qualifying cogenerators at a rate that reflects the costs that the purchasing utility can avoid as a result of obtaining energy and capacity from these sources, rather than generating the energy itself or purchasing the energy or capacity from other suppliers. The term "avoided costs" has been defined by FERC as the costs to an electric utility of energy, capacity, or both, that but for the purchase from a qualifying facility, the electric utility would generate or construct itself or purchase from another source. "Avoided costs" include the fixed and running costs on a utility system that can be avoided by obtaining energy or capacity from a qualifying facility. An electric utility's "avoided costs" are primarily fuel cost for production of energy and capital cost of facilities for generation capacity. The amount a utility will pay a cogenerator for purchased electricity produced by the cogenerator is equal to or is a percentage of the utility's "avoided cost" as decided by agreement contract between the utility and cogenerator, or as set out in a rate schedule published by the utility.

6. ECONOMICS. Cogeneration plants are capital intensive and high maintenance facilities. However, cogeneration can be economically justified if the savings in electrical energy costs, resulting from the use of cogeneration as compared to purchase of electricity from a utility, offset the costs of the cogeneration facility capital investment, added fuel usage, added operation, and added maintenance.

6.1 FUEL SAVINGS. Using cogeneration, there is no fuel saving when compared to the use of boilers for the production of steam for process or environmental heating/cooling systems. There is a fuel saving for production of electricity, by use of cogeneration as compared to non-cogeneration systems, if the exhaust heat or steam from the prime mover is used by other process or environmental heating/ cooling systems.

6.2 COMPETITIVE SYSTEMS. The basic cogeneration systems that provide the means to utilize exhaust heat from the prime mover are the back pressure steam turbine, gas turbine, combined cycle, or reciprocating combustion engine. A cogenerator using only condensing turbine generator equipment cannot compete economically with an electric utility using the same type of equipment because of the economics of large scale operations. The utility's large condensing steam turbine generators operating at high initial pressure and temperature are much more efficient than would be a cogenerator's small condensing steam turbine generators operating at lower initial pressures and temperatures. However, condensing steam turbine generators can be economically combined with noncondensing or extraction turbine generators if the noncondensing equipment is utilized to the extent that fuel savings more than offset the increased cost of

operation of the condensing equipment. The noncondensing and condensing equipment may be combined into single machines such as automatic extraction condensing turbine generators.

6.3 POWER TO HEAT RATIO. A gauge for match of the cogeneration system with the facility heat or steam and electric demands is often expressed as the power to heat ratio. This ratio is defined as the ratio of the power generated to heat available for process or environmental heating/cooling systems. The higher the power to heat ratio, the higher will be the efficiency of cogeneration or economic return on investment capital. Table 34 shows typical power to heat ratios of cogeneration systems.

6.4 ECONOMIC VARIABLES. The application of cogeneration to a facility is site specific insofar as economic evaluation is concerned. The evaluation will require complete information for the facility concerning electricity and steam (or heat) usage and load demand on an hourly basis throughout a typical year. The annual costs of fuel and purchased electricity must be determined for each alternate system to be considered, including an alternate without cogeneration. Also, for each alternate system considered, a determination must be made of total capital investment cost, annual operating costs, and annual maintenance labor, parts, and material costs. Depending on the type of evaluation used, periodic replacement costs and salvage value may need to be determined.

6.5 ECONOMIC EVALUATION. The economic evaluation of the various alternate systems is best done on a life cycle cost basis and by a present worth type analysis. For a complete description of life cycle costing, modes of analysis, methods and procedures for analysis, and choice of most economical alternate, refer to National Bureau of Standards Handbook 135, Life-Cycle Cost Manual for the Federal Energy Management Programs.

	Backpressure Turbine Generator	Gas Turbine	Combined Cycle ¹	Diesel Generator
kWh/million Btu steam	50 to 1	200 to 1	250 to 1	400 to 1
Btu power/Btu steam	0.171	0.683	0.853	1.365

(1) Gas turbine, steam generator, and backpressure turbine generator

Table 1

Typical performance of cogeneration systems power to heat ratio

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A 285/A285M-82 Specification for Pressure Vessel Plates, Carbon Steel, Low-and Intermediate-Tensile Strength.

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