BCHP DESIGN FOR DUAL PHASE MEDICAL COMPLEX

M. Meckler

P.E., CPC, Director, Los Angeles Power Association; Fmr. Adjunct Professor Engineering, CSUN; President/CEO, Design Build Systems (DBS), 10573 West Pico Blvd #200,Los Angeles ,CA 90064, U.S.A.

ABSTRACT

Comprehensive value engineering conducted for a Midwest (USA) developer client focused upon their architect/engineer proposals for a nominal 100,000 sq. meter medical facility comprising under Phase 1, two 12 story medical office towers and an adjacent six (6) story hospital. Client's architect-engineers had originally proposed constructing separate central heating and cooling plants for each of their (i.e., originally designed) Phase I buildings. Phase I plant layout and interim study results demonstrated significant building space and annual owning savings over conventionally designed individual (i.e., in-situ) building heating and cooling plant and incorporated gas and steam turbine driven chillers and integrated gas turbine driven synchronous generator resulting in an estimated 2.6 year simple payback. However, subsequent client Phase II project scope expansion undertaken prior to commencing above referenced Phase I BCHP plant construction required major design changes. The subsequent Phase II redesign resulted in the elimination of higher cost heat recovery steam generator which was replaced with a low cost novel hybrid steam generator utilizing a non-toxic, hot-oil energy recovery system; replacement of costly condensing steam turbine with a less expensive combination serial back pressure steam turbine and indirect single stage absorption chiller bottoming cycle; the later sized for the additional Phase II new office tower subsequently required by client all without exceeding Phase I project budgetary criteria.

KEYWORDS

Steam generator, distributed generation, hybrid heat exchanger, cogeneration, power, thermal energy storage, thermal heat transfer fluids, boiler, medical buildings

INTRODUCTION

Recent US interest in DG has intensified as a result of ongoing concerns about near term utility deregulation and related power shortages now being experienced in California and elsewhere in the US Publications[1,2] sponsored by the DOE and others[3] directed to major US building owners/managers, architectural engineers, utility customer representatives, etc., are intended to position integrated natural gas and electric systems as the "ultimate win-win scenario" has natural gas cooling "experiencing a significant renewal[11], thereby opening numerous opportunities for new gas cooling currently comprising only 20% of the total US HVAC markets, while also focusing on real time energy cost[4], energy flexibility and enhanced overall system benefits for owners on a case by case basis.

Recent BCHP initiatives in US comprised of government, DOE, association, manufacturer, energy service company and utility stakeholders, advocates of on-site/near-site power generation, energy recovery, energy management and utilization for commercial, institutional, multifamily and community buildings. BCHP systems incorporate such natural gas cooling technologies as absorption and natural gas engine-driven chillers to provide sensible and latent cooling, and thermally regenerated desiccant dehumidifiers to provide latent cooling by removing moisture.

As a result, significant immediate and near-term opportunities for natural gas and integrated cooling systems through DOE's BCHP initiative efforts have evolved. Natural gas-based DG[3] technologies such as fuel cells, micro-turbines, gas turbines and reciprocating engines have the potential to account for 20 percent of the electricity generated in the nation by 2020. Additionally, the efficiency and customer benefits of DG[3] installations can be significantly enhanced through directing waste heat streams to cooling and/or dehumidification equipment configured as integrated systems[1,2] allowing improved energy efficiency, cost effectiveness in combination with the full potential of both DG and cooling technologies.

Midwest Medical Complex

As is often the case in designing a major medical facility, plans and circumstances inevitably change. Such was the case with a new Toledo, Ohio, USA medical complex[5,6] that under Phase II included along with earlier described hospital and medical office tower, a second 12-story medical office tower that would operate with an estimated combined annual budget of $2 million (US).

The A/E's firm originally retained by our client proposed three separate central heating, ventilation and air-conditioning (HVAC) plants for the nominal 100,000 sq. meter medical facility. After DBS performed a value-engineering analysis of Client A/E's Phase I proposal, it recommended the installation of a central BCHP plant employing a gas turbine and electric centrifugal chillers[6] thereby eliminating three separate mechanical equipment rooms and freeing up operating staff while providing more usable building space.

Fortunately, construction of the Phase I plant was delayed and in time, our clients decided to incorporate an additional medical office tower. When asked to reevaluate the original Phase I design, DBS determined that the new medical tower would require an additional 5623 KJ/s of cooling, 3983 MJ/s of gas-fired space heating and 135 MJ/s of domestic hot-water heating-capacity. When DBS re-drafted plans for the Phase II BCHP plant design, it incorporated a innovative hot-oil high-temperature energy-recovery system also incorporating a low cost HRSG replacement within the prefabricated gas-turbine-driven generation unit illustrated in Figure 3.

Redrawing the Plans

The above referenced hot-oil HT heat-recovery system employed a HOTF that remains an oil when rated for optimal service at 316˚ C, as shown in Figures 1 and 2, and allowed replacing earlier proposed conventional HRSG[6] shown in Figure 3 with a lower cost, and the more efficient "modified" HRSG, illustrated in Figure 4.

The HOTF planned for use in the diagram (illustrated in Figures 2 and 3) is rated for service to 316˚C. It is highly efficient, thermally stable and cost-effective. It is non-toxic and safe to use, easy to dispose and safe to handle according to its manufacturer, a key factor in selecting it for this application.

Unlike conventional heat transfer fluids, the HOTF selected will not cause hard carbon formation on heated surfaces. Most conventional heat transfer fluids, when severely overheated, produce sooty carbon at the firm layer. Much of this carbon thus formed then adheres to the heated surface and bakes on, forming a crust. As layer-upon-layer builds up, heat transfer suffers and in many cases flow is also impaired. Although quite difficult to remove without scraping, sandblasting or using chlorinated solvents, crusted carbon thus formed can ultimately break loose, and large chunks can circulate through the system impending flows and fouling components, etc. Where fouling is extreme, heater tubing and electrical elements can stress and prematurely fail. Under similar extreme overheat conditions, the selected HOTF, however, evolves small carbon granules and while these granules remain in suspension and are easily filtered out.

Finally the above referenced HOTF operates a low vapor pressure, (i.e., approximately less than 1/3 of an atmosphere, etc.) at its maximum operating temperature of 316˚C. This feature together with its fluid's characteristic low pressure drop combine to provide the BCHP plant designer considerable latitude in the selection of lower overall cost hybrid H.X. as compared with employing the more costly HRSG boiler tube sheet surface configuration illustrated in Figure 3.

Hybrid Steam Generator:

Conditions that justify selection of a hybrid heat exchanger illustrated in Figure 2 versus conventional HRSG steam generators include the following:

- High operating pressures required – Pressure in excess of 28 to 33 kg/cm^2.
- Full modulation with rapidly fluctuating loads – where full modulation of steam output, not just fuel is desired, and full range response time of the hybrid heat exchanger steam generator arranged as shown in Figure 3, is within 15 seconds(s) or less. Conventional HRSG units having more thermal mass often require considerably more response time.
- High-output turndown ratio – hybrid HX steam generator generally offer turndown ratios as high as 12:1. With wide load swings expected, this can provide an important advantage.
- Rapid startup – for those applications where it is advantageous to go from cold start to full-steam output in typically 5 minutes, the proposed hybrid HX steam generators quick steaming capability provides advantages unmatched with conventional HRSG's.
- Small size, low weight – perhaps the greatest advantages the hybrid HX steam generator provides over HTSG's in BCHP steam heating applications are its compact size, which along with modular construction, permits substantial savings in both construction and installation costs for both retrofit and new facilities.

Phase II Medical Office Tower

Additionally, a nominal 5623 KJ/s single-effect lithium-bromide (LiBr) absorption chiller is utilized as a bottoming cycle for a steam-turbine induction motor-type generator in lieu of the originally proposed condensing steam turbine driving a synchronous generator. The remaining major equipment types[6] employed under the original Phase I design remained the same except for sizing and included: the deaerator, hot and chilled TES gas-fired heating and domestic service boilers, on-site cooling towers and related appurtenances. Sizing considerations on some components, however, were revised so that the redesigned Phase II design can satisfy heating and cooling loads below a peak of 3130 KW.

Operational Outlook

The originally designed Phase I driven centrifugal chiller remained a nominal 7020 KJ/s unit, driven by a gas turbine that produces 1163 KW at an inlet air temperature of 15˚ C. This temperature is achieved by means of a precooling chilled-water coil (not shown) located in the inlet turbine air duct. The chiller operates with a standard 5.6˚ C temperature across the absorber condenser. Two nominal 7029 KJ/s cooling towers serve both the gas-turbine-driven and steam-turbine/motor-driven centrifugal chillers.

Available chiller-turbine exhaust heat is ducted to the hot-oil HRSG section of the gas-turbine cogeneration unit as illustrated in Figure 4. The resulting superheated steam then drives an induction motor generator with a power output of 1630 KW also connected in tandem with a chiller steam turbine. Alternatively, the induction motor can also drive the centrifugal ice chiller through clutching arrangements (not shown) which serve to decouple shaft from the steam turbine and utilize it to drive the nominal 520-ton centrifugal ice chiller, when necessary.

The modified packaged cogeneration unit consists of a gas turbine, a generator, a turbine exhaust system and a hot-oil heated HRSG interconnected with extraction coil located duct exhaust gas as shown in Figure 4.

The nominal 1.5-MW generator remained the same as originally planned under Phase I[6], with exhaust gases combined directly with those available from the gas-turbine driven centrifugal chiller[6] (not shown). The configuration is used to produce superheated steam employing the closed-circuit hot-oil HT heat-recovery system HRSG.

By using a compact hot oil heated heat exchange means as shown in Figures 1, 2 and 4 etc., DBS was able to replace a more expensive conventional HRSG with a substantially lower cost hybrid heat exchanger (see Figure 2). The backpressure on both gas turbine drivers at their point of discharge shown in Figure 4 was also reduced by means of a lower pressure loss companion flue gas hot oil extraction heat exchanger as shown in Figure 1. This resulted in a higher net available gas turbine output shaft hp than available under the Phase I plant design.

Referring to Figure 4, notice that the turbine exhaust system incorporates a flow-diverter valve and supplementary direct gas-fired duct burner located upstream of the hot-oil steam generator. Superheated steam produced at 13381 Kg/hr. in the HRSG, is piped to the steam turbine generator that generates a power output of 1630 KJ/s.

The nominal 7020 KJ/s cooling tower yields 189 l/s of cooling water at 29˚ C for the single stage absorption chiller condenser that operates at 8.3˚ C. to permit higher efficiencies for the combined chiller. Also the serial-flow chilled-water return to the BCHP plant was designed to first enter the single effect absorption chiller, prior to discharging to the turbine-driven centrifugal chiller, etc.. The deaerator serves to remove oxygen and carbon dioxide from make-up water and condensate and, hence, reduces corrosion.

Cool Storage

The TES system also remained the same size and type as originally planned under Phase I and employed a plate-and-frame heat exchanger and two TES tanks – 8.1 m in diameter and 4.9 m high, each with a nominal volume of 243.247 ℓ. The tanks are filled with "ice balls" comprising 4-inch diameter plastic spheres filled with water and a freeze-point-enhancing nucleating agent. During the night, TES build cycle ice cools the glycol water solution to 5.6˚C. Water within the above referenced plastic sphere freezes, storing cooling energy.

During the day discharge cycle the TES glycol solution is warmed by return water that has passed through the heat exchanger, cooling the glycol for use in pre-cooling inlet turbine air and for cooling building occupancies. Support TES equipment includes an ice-inventory-control system, a 2457 KJ/s cooling tower and chilled-water, glycol and condenser pumps.

Steam generated form the closed-circuit HOTF heat-recovery system serves the single-effect nominal 5623 KJ/s absorption chiller, enabling it to generate cooling for the additional office towers. In addition, its use offers redundancy for scheduled maintenance needs of the serial-flow interconnected nominal 7020 KJ/s turbine-driven centrifugal chiller. When demand drops below 1,462 KW, only the modified gas-turbine cogeneration unit operates. When the load is greater than 1,462 KW, the steam-turbine induction motor generator comes automatically on-line. When insufficient heat is available to produce steam for the additional power, the gas-turbine unit's integral supplementary duct burner fires and generates required heat. The burner will only fire if the amount of steam available is inadequate.

Another important piece of the system is a diverter valve (see Figure 4) located in the exhaust-gas ductwork downstream of the gas turbine unit. The diverter valve is equipped with an exhaust silencer and its own bypass stack to exhaust the combined gases of both turbines whenever necessary. Exhaust gases are diverted to the atmosphere through the bypass stack during heat-recovery equipment maintenance, allowing the turbine/generator illustrated in Figure 4 to remain in service. The diverter valve can also modulate exhaust gases into HOTF heat-recovery generator to match steam generation with power demand.

The specified steam-turbine generator is expected to produce approximately 1,630 KW at 13,608 Kg/hr. of heated steam input. In the summer, the generator recovers heat from both the centrifugal chiller and the cogeneration unit to produce its rated power output. In the winter, the generator produces only 50 percent of its rated output. Therefore, when the combined load exceeds 3130 KW, incremental power has to be purchased from local utility. The real cost savings, however, comes from reduced electrical demand charges resulting from the expanded BCHP plant utilizing the indirect-heated single-stage absorption chiller. Approximately 85 percent of the total required annual electrical power will be produced on site by the combined-cycle cogeneration BCHP plant and a mere 15 percent will have to be purchased from the soon-to-be-deregulated outside utility. This mix still results in a favorable combined annual BCHP operational cost. Therefore no supplemental on-site generator capacity was added to fully satisfy the additional Phase II medical office tower.

In Summary

Although neither the hot-water converter capacity nor the steam-turbine generator unit were optimized, simple payback for the extended BCHP facility was slightly lower than original Phase I projection of 2.1 years.

The redesigned Phase II BCHP plant contained features also intended to reduce annual operating and maintenance costs while achieving significant first-cost savings and satisfying client redundancy concerns. Use of Paratherm NF fluid offers a number of benefits as pointed out earlier. Such fluids are highly efficient, thermally stable, cost effective, nontoxic, safe to use and easy to dispose of.

Unlike most conventional heat-transfer fluids, Paratherm NF does not cause hard carbon formation on heated surfaces. Without layers of carbon building up, the common problems of heat transfer and flow impairment are eliminated.

As for the usual problems of carbon chunks breaking loose, circulating through the system, impeding flows and fouling components are also avoided. Although the fluid evolves small carbon granules when overheated, these granules remain in suspension and can be easily filtered out. Additionally, the selected fluid operates at a low vapor pressure, which is approximately less than one-third of an atmosphere, at its maximum operating temperature of 316° C.

This feature, together with the fluid's characteristic low pressure drop, combine to provide the BCHP plant designer considerable latitude in being able choose lower overall cost equipment as opposed to employing conventional heat-transfer steam generators.

The results of comparative analysis of above referenced Phase I BCHP for Midwest (USA) hospital and medical office complex comprising of three buildings: a six-story hospital and two identical 12-story office towers presented in an earlier study[6] demonstrated substantial benefits in favor of BCHP, an estimated installed first cost savings of $906,760 (US) and a sizable reduction (of US $98,550) in annual maintenance cost resulted from replacing four separate mechanical equipment rooms with a single integrated BCHP plant.

As markets open and generation assets change hands, on-line energy trading through the Internet is also projected to soar. Most online energy players have concentrated on trading wholesale power and gas. The overall electronic energy trading market, however, is estimated to grow to about $14 billion (US) by 2002, up from $4.9 billion (US) in 1998. For buyers and customers alike, a major attraction of the online systems is the potential for lower transaction costs. With such lower costs, and problems with delaying construction of electric utility plants due to local environmental concerns, the future of BCHP plants within the US now looks brighter than ever.

References

[1] Application Engineering Manual for Integrated Systems Design, American Gas Cooling Center (AGCC), Washington DC, October 1999

[2] Technology Transfer Workbook Workshop: Integrated System Design, American Gas Cooling Center (AGCC), Washington DC, October 1999.

[3] Chellini, Roberto-New Siemens Approach to DG Marketplace, Distributed Power, Diesel and Gas Turbine Publications, Waukesha, WI, USA, November/December 2000.

[4] Meckler, Milton-Real Time Savings, Consulting-Specifying Engineer, Chicago, IL, USA, July, 1999.

[5] McNeely, Mark - Hospital Cogenerates for Savings, Reliability, Distributed Power, Diesel and Gas Turbine Publications, Waukesha, WI, USA, November/December 2000.

[6] Meckler, Milton - Cool Prescription, Consulting-Specifying Engineer, Chicago, IL, USA, April 1997.

Nomenclature

m = meters
ℓ = liters
ℓ/s = liters/second
KJ/s = kilojoules/second
MJ/s = megajoules/second
ºC = degrees centigrade
KW = kilowatts
$Kg/_{cm}^2$ = kilograms/square centimeters
MW = megawatt
DBS = Design Build Systems
A/E = architect-engineer

HRSG = Heat recovery steam generator
DOE = US Department of Energy
HVAC = Heating, Ventilating, and Air-Conditioning
DG = Distributed power generation
HX = Heat exchanger
HT = High temperature
TES = Thermal energy storage
BCHP = Building Cooling Heating Power
HOTF = Hot Oil Transfer Fluid

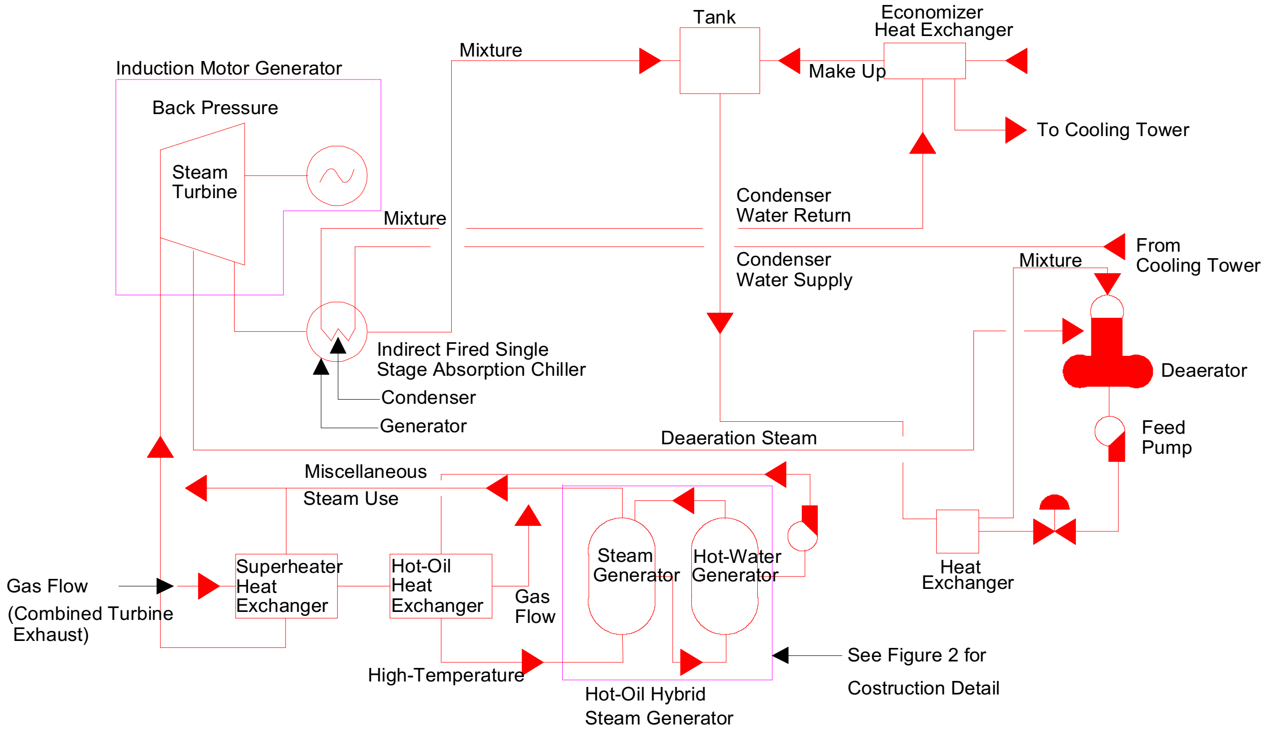

Figure 1: Combined Cooling/ Heating Plant. A hybrid steam generator enables the medical complex's cogeneration plant to operate more efficiently. The detail (above) shows how the hybrid unit is connected to the overall plant (left, at bottom).

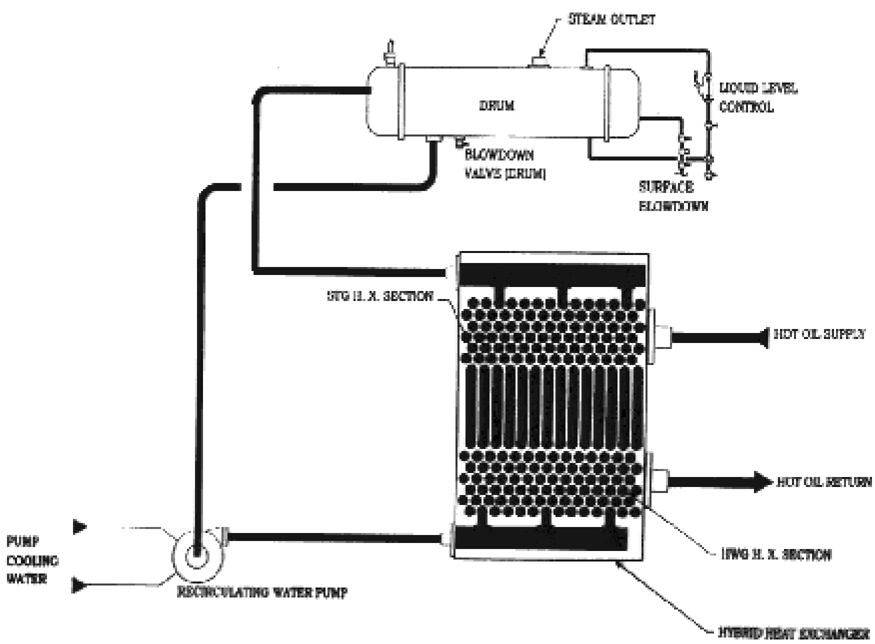

Figure 2: Hybrid Steam Generator

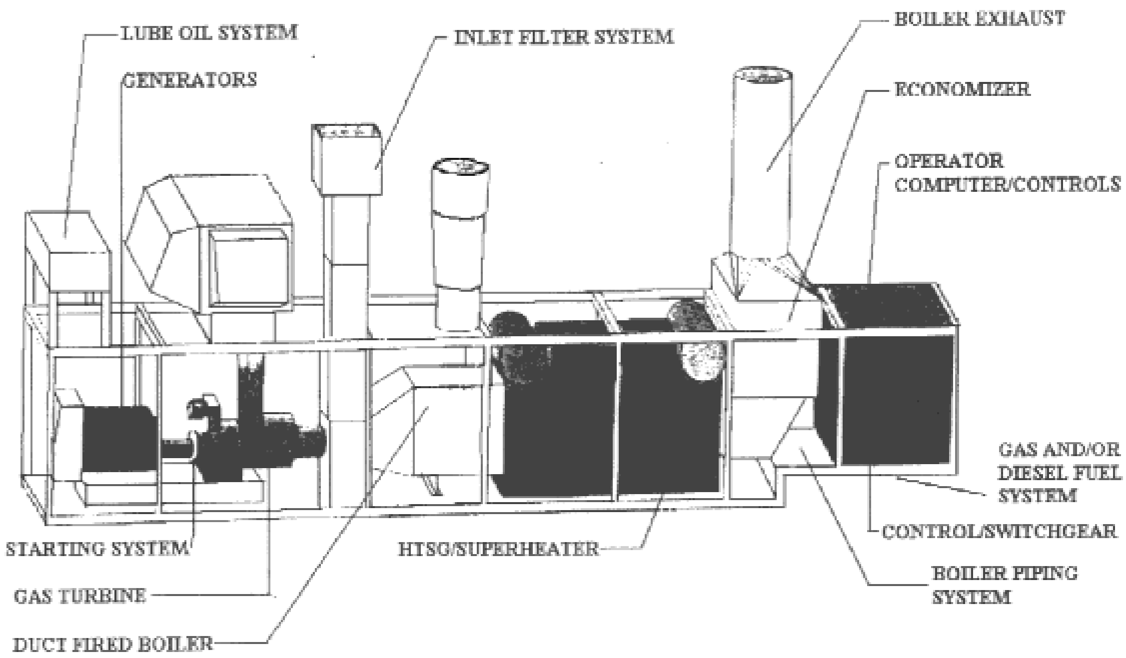

Figure 3: Conventional Gas Turbine. Cogeneration Unit

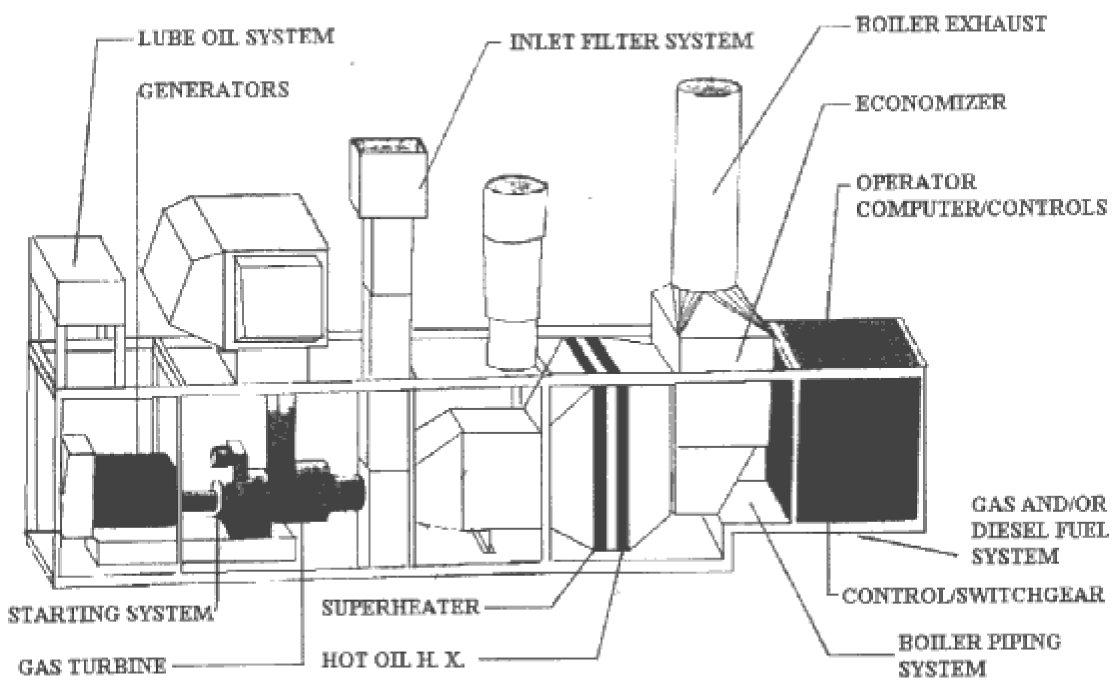

Figure 4: Modified Gas Turbine. Cogeneration Unit