



CHP APPLICATIONS

Aeroderivative Gas Turbines Driving CHP Applications

Helmut List

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ABSTRACT

Over 800 units installed in cogeneration, with over 26 million operating hours, makes the GE aeroderivative gas turbine one of the most experienced technologies in the cogeneration world. The high operational flexibility of aeroderivative technology opens a wide range of solutions for industries such as pulp and paper, food and beverage, refineries, or chemical industry—applicable for continuous operation as well as for daily start/stop in factories with shift operation. With the highest power density in the gas turbine and reciprocating engines world and the standard package inside acoustics enclosure, aeroderivatives are the preferred solutions for installations with limited space availability and within residential areas, as demonstrated in multiple installation for hospitals, universities or airports—providing power, heating, and cooling.

The exchange program for maintenance work allows factories to return to full production as soon as three days after gas turbine shut-down. Fast ramp rates, highest efficiency even at partload, five-minute start capability, and multiple start/stops per day, which are not impacting the maintenance intervals of the gas turbines, allows the operator to drive the gas turbine based on process needs, or at the lowest operational costs.

This paper will address the following topics:

- Aeroderivate performance: heat-to-power ratio, baseload and partload efficiency, gas turbine availability/reliability, emissions
- Operational flexibility: fast start capabilities, ramp rates, load following capabilities
- Cost considerations: O&M costs, footprint, installation time

AERODERIVATIVE GAS TURBINES DRIVING CHP APPLICATIONS

OFFERING ADVANTAGES THAT HEAVY DUTY GAS TURBINES AND RECIPROCATING ENGINES CAN'T MATCH

GE Power is a world leader in heat and power generation, with deep domain expertise to help customers deliver thermal heat and electricity. GE aeroderivative gas turbines have a remarkable history in operating combined heat and power plants (CHP) all over the world. With a total number of >150 million operating hours, GE aeroderivatives have a very long record of experience in this technology. More than 2,100 shipped units and >100 million operating hours makes the LM2500 a leader in this segment. Almost 20% of all LM2500 units installed worldwide are operating in CHP/Cogeneration applications.

Even more experience in the CHP and cogeneration business is demonstrated by the LM6000, where 30% of the 1,320 shipped units with >40 million operating hours drive a CHP plant worldwide. In Europe, where most of the cities are supplied by district heat, more than 60% of the installed units are operating in a CHP/Cogeneration plant.

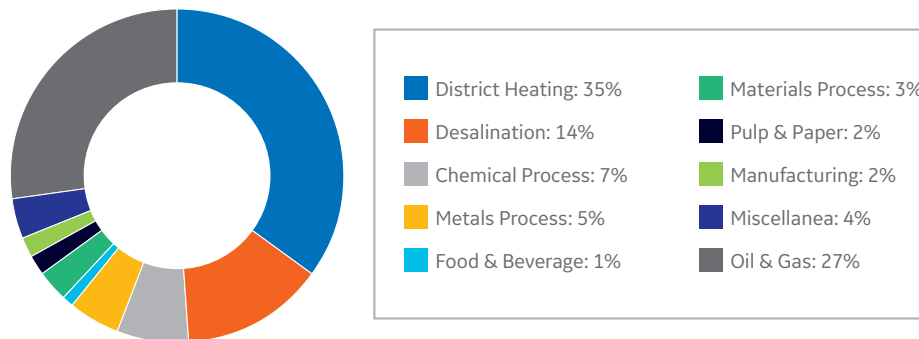


Figure 1 – GE Turbine in CHP Applications

WHY AERODERIVATIVE GAS TURBINES?

Derived from the aircraft engines, the aeroderivative gas turbines combine the advantages of heavy duty gas turbines and gas engines in terms of performance, operational flexibility, and cost.

PERFORMANCE

Power Output

GE aeroderivatives offer different sizes of gas turbines with a wide power range starting with 20 MW, which is almost the upper limit of gas engines, up to 130 MW. A heavy duty gas turbine starts in the range of 40 MW upwards, but—due to their high exhaust energy—have a high heat-to-power ratio, which often exceeds the heat requirements of most of the cogeneration applications in the industry, like the food, chemical, paper, mining, petrochemical industry, or smaller installations for municipalities. Especially in district heating networks for municipalities, smaller solutions are preferred to keep distribution losses low.

The exhaust energy of an aeroderivative gas turbine allows it to produce high-quality steam in the high- and medium-pressure range with certain amounts of superheat, which can serve any industrial steam requirements without the need of supplementary firing in the heat recovery boiler. Gas engines have a much lower exhaust temperature, and therefore a significantly lower heat-to-power ratio with limitation to supply high-quality steam to industrial CHP applications.

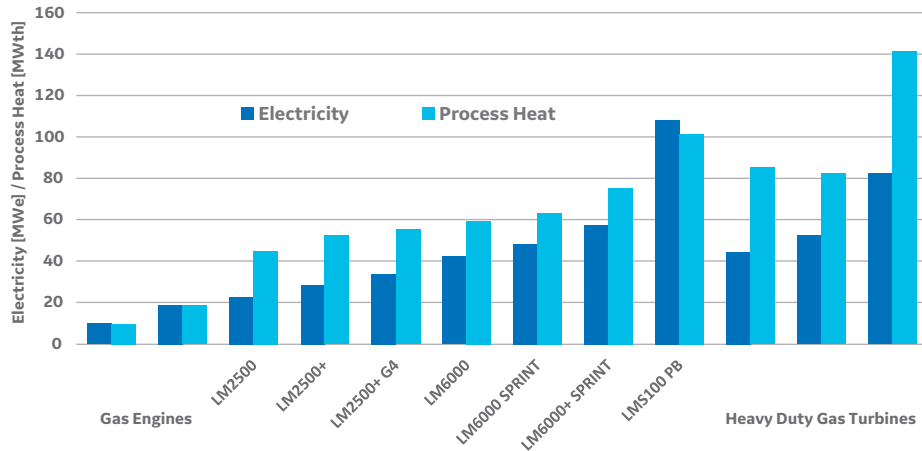
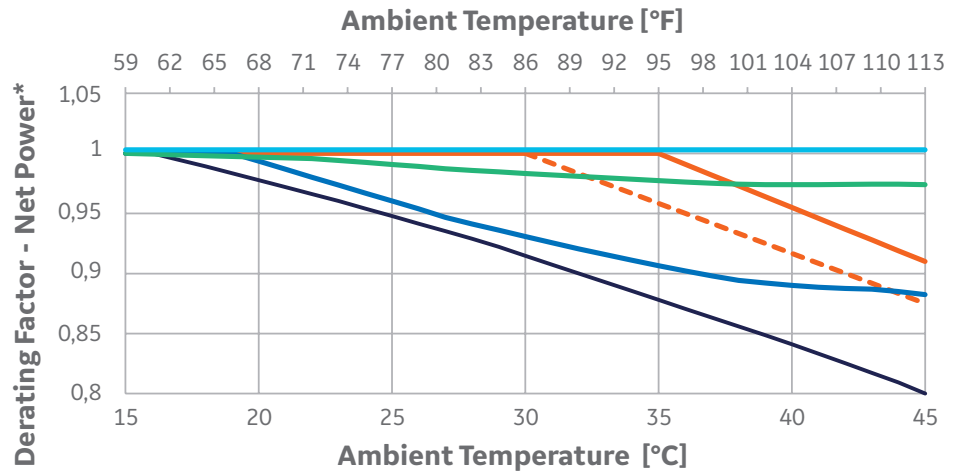


Figure 2 – Electricity vs. Process Heat comparison for a single unit without supplementary firing

In many applications, an aeroderivative gas turbine provides sufficient exhaust energy to provide process heat (cogeneration) and to operate a steam turbine at the same time. The steam turbine configuration and process heat supply depend on the plant requirements, and varies from a backpressure steam turbine with or without process steam extraction to a condensing steam turbine with or without extraction. In such a configuration, the CHP/Cogeneration plant can either provide the maximum process heat at high heat demand like, for example, district heating in the winter, or maximum electric power with low or at least no process heat at high combined cycle efficiency.

The power output of gas turbines derates with increasing ambient air temperatures. However, especially on aeroderivative gas turbines, the derating can be compensated with inlet conditioning such as evaporative cooling or inlet-air chilling and wet compression (SPRINT). In such a configuration the GE aeroderivatives show equivalent steady power output over a wide range of temperatures.

The inlet conditioning system can also be used as power augmentation to improve power and efficiency at lower ambient temperatures.



* Chilled cases include auxiliary chiller load.

- Small Gas Engines
- - - Large Gas Engines
- HD GT
- Aero GT - Wet System (EVAP and wet compression)
- Aero GT - Dry System (electric chiller)
- Aero GT - Dry & Wet System (electric chiller and wet compression)

Figure 3 – Derating Factor vs. Ambient Temperature

EFFICIENCY

The simple-cycle electric efficiency of GE aeroderivative gas turbines reaches up to 43% at baseload and is still higher in efficiency at 50% partload as the same size of heavy duty gas turbine at baseload.

The catalog performance data for gas engines are mainly given at shaft output. For the net power and efficiency of the piston engines, the generator losses, auxiliary losses, as well as the 5% tolerance in fuel consumption, must be considered in the net plant power and efficiency. The guaranteed net plant efficiency of large reciprocating engines in simple cycle are in the range of 45%, and even lower for smaller units.

Gas turbine performance data are based on power at the generator terminals and do not allow this tolerance for guaranteed performance data.

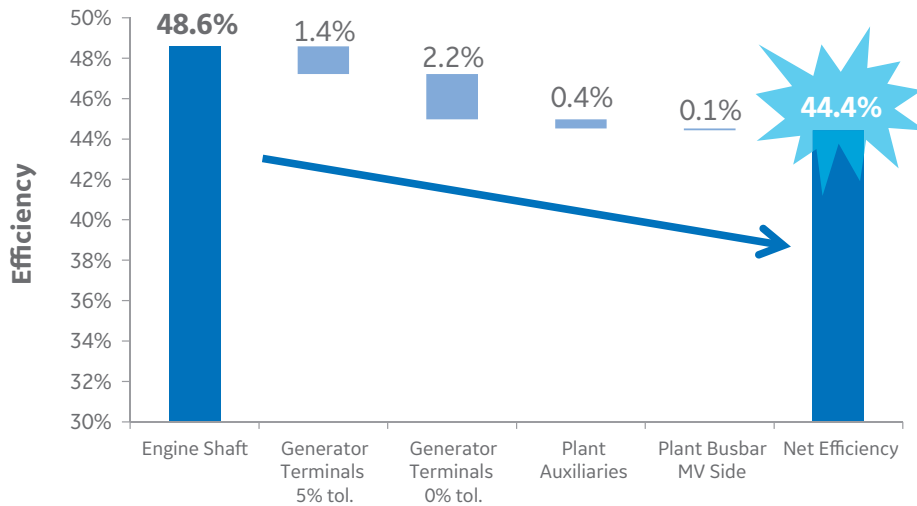


Figure 4 – Large Dual-Fuel Reciprocating Engine Efficiency Steps

In a CHP plant, an aeroderivative gas turbine combined with a backpressure steam turbine reaches up to 50% electric efficiency, which is 5% higher in net plant efficiency compared to large high-efficiency reciprocating engines.

Reciprocating engines recover heat from multiple sources, like the heat rejected to the jacket water, the lube oil, and the intercoolers. The maximum temperature of the jacket water is in the range of 90°C/195°F and therefore has limited usage in big district heating (DH) networks for cities with higher supply temperature requirements. The CHP efficiency of reciprocating engines serving in DH applications drops below 76% with supply temperatures of 130°C/255°F and return temperatures of 80°C/175°F. In such an application an aeroderivative gas turbine reaches up to 90% CHP efficiency—14% higher compared to reciprocating engines.

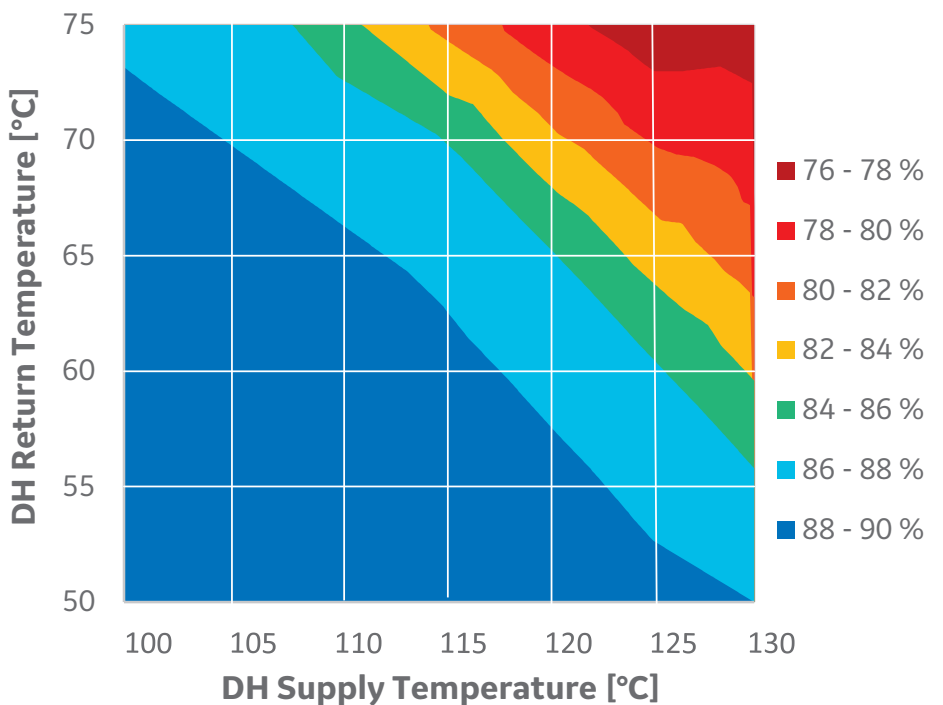


Figure 5 – Reciprocating Engine District Heat – CHP Efficiency

AVAILABILITY

Aeroderivative gas turbines have among the highest availability of any thermal power technology. The core engine can be replaced in a few days for a major inspection, providing a unique plant availability of over +98.7% (source: ORAP data). This directly follows the maintenance practices in the aviation industry, where an aircraft never loses service availability for engine maintenance; the engine is simply swapped out overnight, leaving the aircraft to resume a profitable operation.

Gas engines require routine maintenance stops every 500 to 2,000 hours (depending on the installed system) for oil and filter changes as well as for valve clearance and ignition checks. The availability of gas engines is therefore, in general, significantly lower than in the gas turbine technology. The average availability of reciprocating engines is in the range of 93%, which is at least 5% lower, compared to aeroderivative gas turbines.

For a 160 MWe power plant in a combined heat and power system the cumulative availability of three aeroderivative units is still above 95%. A multiple unit installation of 10 large reciprocating engines with a single availability of 93% results in an overall plant availability of less than 50%.

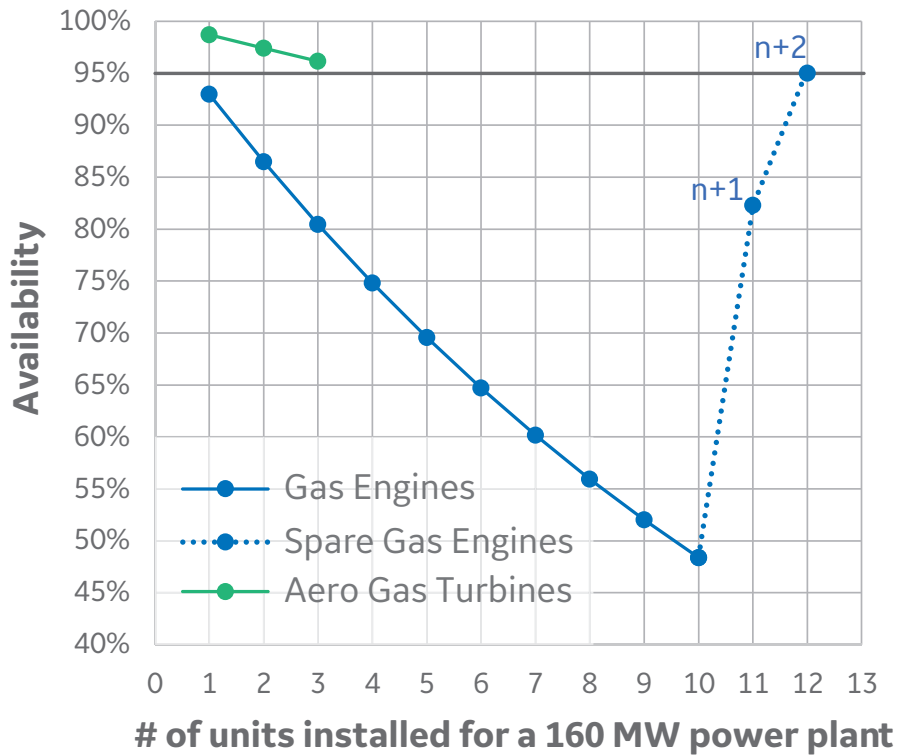


Figure 6 – Impact of Multiple Units on Availability

To achieve equivalent availability, it requires two more reciprocating engine units (spare units) resulting in a 20% oversizing in plant size and CAPEX.

RELIABILITY

Derived from GE’s line of aviation turbines, the “Land and Marine” turbines, thus the “LM” designation, are built for highest possible reliability. The mission in the aviation world is very clear: every single part of an aircraft engine must fulfill the highest possible reliability as no airline and at least no passenger can accept an engine outage, neither during start nor during operation up in the sky. As each part of an aeroderivative core-engine follows the same supply chain as aviation, the GE aeroderivative gas turbines provides almost the same reliability to all LM models. As shown in the SPS ORAP database, GE aeroderivative gas turbines offer 99.9% operational reliability and +99% start reliability.

FUEL FLEXIBILITY

GE aeros can operate on gas and liquid fuels without significant power derate or pilot fuel requirements. Gas turbines can operate on natural gas, LPG, or diesel, among many other fuels, switching between these fuels without stopping and without power reduction. They use the same combustion system for a wide fuel spectrum, starting with lean gas, high hydrogen content, coke oven gas, butane, LPG, light liquid distillates up to diesel fuel or aviation kerosene, giving customers options to switch between fuels when economically preferred, as well as providing reliable power generation capabilities with fuels coming from different sources.

While medium-speed diesel reciprocating engines could potentially be made to run on fuels such as ethane, butane and propane, the result is commonly a significant performance drop and output derating. Only aeroderivatives can operate on these non-traditional fuels without suffering any performance and output derating. They can easily switch from running on 100% diesel to 100% natural gas, whereas a medium-speed dual-fuel reciprocating machine will still require an expensive pilot liquid fuel when burning natural gas.

EMISSIONS

Aeroderivatives use best-in-class combustion systems and can offer 15 or 25 ppm NOx (depending on the specific model, fuel, and configuration), without the need of SCRs (selective catalytic reduction) or CO oxidation catalysts to satisfy strict EPA, World Bank, and international environmental requirements. Stack heights are much lower, and there is no visible smoke due to more complete combustion in the gas turbine compared to gas engines.

Combustion in reciprocating engines can produce almost 10 times more NO_x, seven times more CO, six times more particulate matter, and six times more VOC than aeroderivative turbines, even when operating with the same fuels and under the same conditions. This necessitates the use of SCRs and/or stack extensions in most gas engine installations. With an SCR in place it takes up to 20-30 minutes—depending on the emission guarantee level—to reach emission compliance.

NOISE EMISSIONS

Low frequency mechanical vibrations in the range of 110dBA+ from reciprocating piston movement are transmitted to the surrounding buildings and felt as ‘humming/knocking’ sound. This is a major disadvantage for an application where high-end premium residential properties are being developed. Power plant building will require major sound proofing at significant costs. All aeroderivative gas turbines are packaged inside acoustic enclosures with a standard configuration for 85 dBA and an optional configuration for 75 dBA from the rotating machinery and engineered for installation outdoors, exposed to sun, rain, and snow.

OPERATION FLEXIBILITY

FAST START CAPABILITY

Reciprocating engines require pre-warming, lube oil, and cooling conditions to start, so start time should be assessed for a “hot” and “cold” engine. GE’s aeroderivative gas turbines have a time of cold start to maximum power delivered to the grid in as quickly as five minutes.

Furthermore, during downtime, aeroderivative gas turbines consume no auxiliary loads, while heavy duty gas turbines and reciprocating engines require a considerable parasitic load to maintain start readiness, keeping the engine and the lube oil warm.

The maintenance requirement of heavy duty gas turbines is based on independent counts of starts and operating hours. Multiple starts increase the frequency of maintenance and downtime of heavy duty gas turbines. In addition, for any start, in less than 10-15 minutes (depending on the GT model) a peaking-start factor must be applied, where the factor depends on the hot, warm, or cold condition of the unit. If the unit must be restarted in less than one hour an additional factor reduces the maintenance intervals.

Aeroderivatives have no minimum operating run time or stop time. They can usually be re-started immediately after a shut-down, if required. Furthermore, they have no major maintenance cost penalties for daily starts/stops, providing a proven technology for peaking applications.

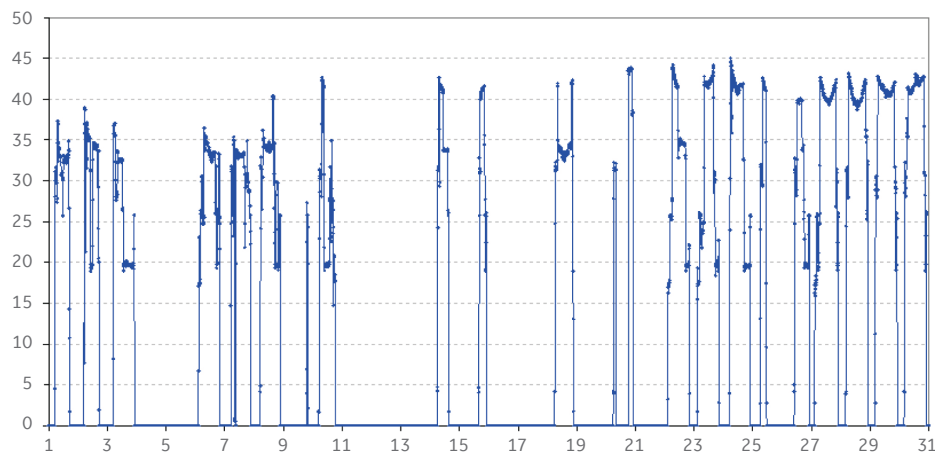


Figure 7 – LM6000 CC-DH Plant – daily dispatching

RAMP RATES

Typical medium-speed reciprocating engines have a ramp rate of about 5 MW/min, due to the engine dynamics and the nature of the combustion system.

GE’s aeroderivative gas turbines have a nominal ramp rate up to 50 MW/min. Another important feature when considering ramp rates is that aeroderivatives have no under-frequency trips, assuring they will remain online, even during the most intense frequency fluctuations.

While fast ramp rates do not affect the maintenance intervals of aeroderivatives, an additional operating factor must be applied to the maintenance consideration for heavy duty gas turbines, independently if the unit is rated on hours-driven or starts-driven maintenance.

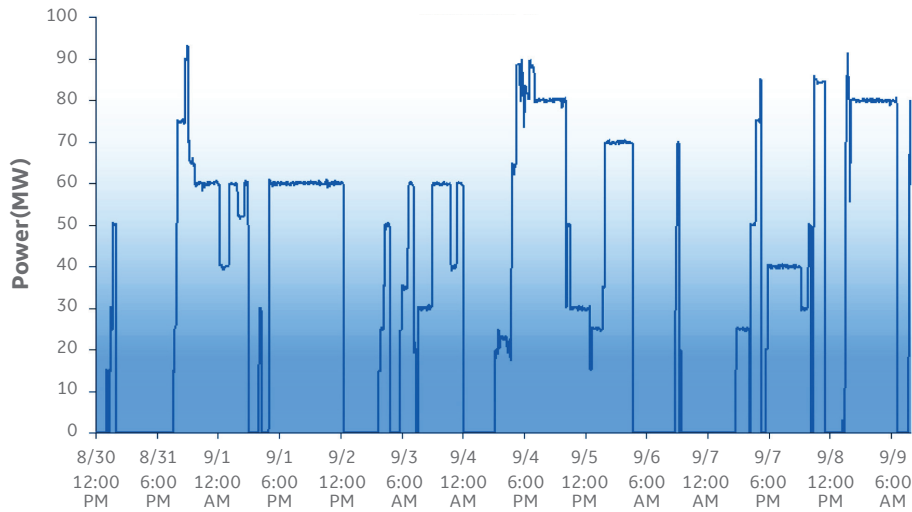


Figure 8 – LM6000 CHP – supporting the energy demand

POWER AND HEAT LOAD FOLLOWING

Combining aeroderivative fast ramp capability with boiler quick response technologies also allows for service of industries, where the sudden loss of power or steam is detrimental to the manufacturing process. Aeroderivatives in a multiple unit configuration—equipped with power augmentation—can recover the power to a minimum requirement during the losses of gas turbines and/or steam turbines in less than two minutes for the worst-case scenario.

Including inlet conditioning and wet compression guarantees equivalent power and heat production over the entire ambient temperature range.

INDEPENDENT POWER AND HEAT

A CHP plant with a steam turbine in place allows the electric power production to be disconnected from the process heat production and gives the operator more flexibility in fulfilling the plant requirements for variation in heat and electricity demand. In a district heating application, for example, such a configuration can much better serve the high continuous heat load during winter time as well as the high electricity demand during peaking periods in the summer while operating with the high efficiency of a conventional combined cycle plant.

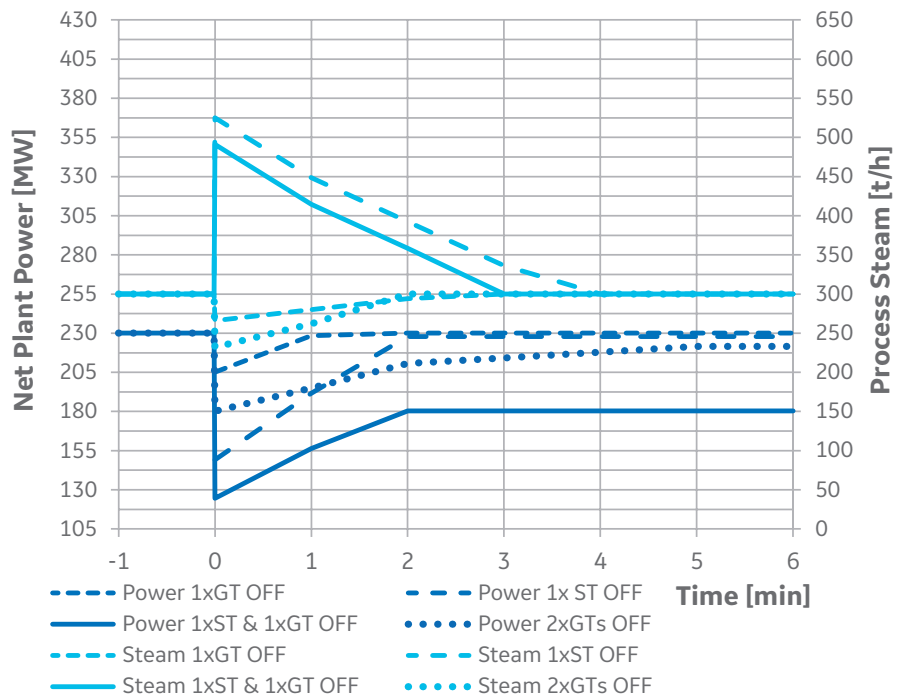


Figure 9 – Power & Heat Recovery

COST CONSIDERATIONS

OPERATION COST

Besides fuel consumption, lube oil consumption in reciprocating engines must also be considered as a consumable cost, further increasing the actual cost of electricity. Reciprocating engines may use up to 400 mL/MWh of lube oil, while an LM2500 will only consume 2 mL/MWh, or approximately 200 times less. Lube oil alone can represent a saving of over 1 million US\$ per year for a 100 MW aeroderivative power plant compared to a reciprocating engine plant.

MAINTENANCE COST

Operating hours of GE aeroderivative gas turbines are counted based on actual operating hours—not considering any factors or equivalent operating hours—and on-condition of the gas turbine. The major overhaul typically takes place at 50,000 operating hours, where the core engine of the gas turbine package is carried out to the depot. With a lease or spare engine during the overhaul, the outage time is reduced to 2-3 days, allowing the customer to continue plant operation. The major overhaul on a reciprocating engine is usually performed at an interval of 12,000 hours and is carried out on-site with a unit downtime of at least 30 days.

As aeroderivative gas turbines require significantly fewer operation and maintenance interventions than reciprocating engines, they also save a considerable amount of man-hours, requiring only 1,800 man-hours of maintenance during a three-year cycle, compared to over 15,000 man-hours for reciprocating engines.

FOOTPRINT

Aeroderivative generator sets have much higher power density—with about 22 times more power output per unit—than high-speed reciprocating engines. Aeroderivatives offer advantage for cost of land, power density, maintenance area, and storage facilities. A GE aeroderivative power plant has a footprint that is one-third to one-quarter that of a typical reciprocating engine plant configuration for equivalent power. Not only are aeroderivative units smaller, but they are much lighter per MW than their high-speed reciprocating engine counterparts.

INSTALLATION

Due to their small size and modular nature, aeroderivatives can be transported, installed, and commissioned more quickly than either heavy duty gas turbines or reciprocating engines. Compared to the aeroderivative LM2500, reciprocating engine transport costs are at least 3x higher due to a factor of 42x weight, adding in cost and special transport considerations for a 100 MW plant. Air freight is not possible for major reciprocating engine components, requiring longer transport times, while some aeroderivative gas turbines can be delivered rapidly by air anywhere in the world.

A significantly deep and bulky foundation for gas engines is required to support a >200 tons dynamic weight.





CASE STUDIES



SILKEBORG KRAFTVARMEVÆK A/S, DENMARK

Operation Pattern

- 4,500 operating hours per year
- 230–250 starts per year

Plant Configuration

- 2x LM6000 PD with frequency control system
- 2x OTSG with SCR and supplementary firing
- 1x Steam turbine
- 1,000 MWh district heating storage tank

Yearly Production

- Electrical production: 450 GWh
- District heating production: 1375 TJ
- NOx emissions: 13-15 ppm



FERRERO CHOCOLATE FACTORY ALBA, ITALY

Operation Pattern

- Electricity for the factory and the city of Alba
- Process steam to the chocolate factory
- District heat to the city of Alba

Plant Configuration

- 1x LM6000 PF SPRINT
- 1x HRSG
- 1x Backpressure steam turbine

Yearly Production

- Electrical production: 400 GWh
- Thermal energy: 350 GWh

CONCLUSION

With over 110 million operating hours and more than 4,000 units shipped, GE's innovation and systems knowledge brings value to a wide range of customers—from commercial and industrial businesses, to municipalities and national governments—creating either new business solutions or expanding the capability of existing facilities.

The operational flexibility of GE aeroderivative gas turbines opens a wide range of CHP applications, providing the high reliability needed in industries like the petrochemistry, pulp and paper, or food and beverage. GE aeroderivatives also demonstrated their capabilities to operate in noise-sensitive areas in cities, next to hospitals, universities or urban areas.



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