Enabling Renewable Penetration Using the LM2500XPRESS – GE Gas Power's Aeroderivative Solution

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EXECUTIVE SUMMARY

Aeroderivative gas turbines derived from advanced aviation technology can provide reliable power that is cleaner, cheaper, and provides better grid stability than that produced by reciprocating engines , enabling grid operators to support greater penetration of renewable energy to the grid.

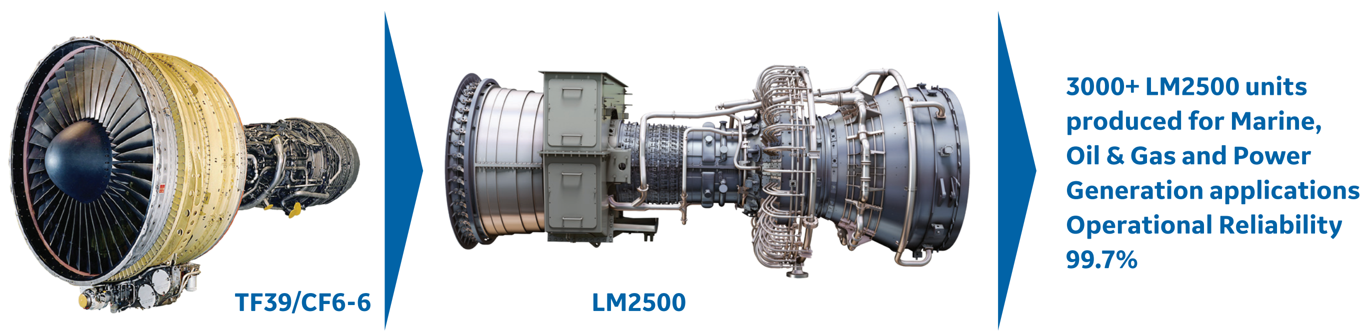
The following points are detailed in this document:

- **Fast start & cyclic operation:** Aeroderivative gas turbines can be started and loaded up to full load within five minutes from cold iron, with no maintenance penalty for daily start/stop operation
- **Grid stability & frequency control:** By delivering excellent grid stability and frequency control for power generators and consumers, aeroderivative gas turbines help avoid blackouts and result in lower maintenance costs associated with grid-connected equipment
- **Seamless renewables integration:** While the high penetration of renewable power—such as wind or solar—greatly reduces grid stability, aeroderivative turbines provide the excellent frequency stability required to support the use of more renewables on the grid.
- **Reliability & availability:** Based on aviation technology, aeroderivative turbines provide reliable operation, with a fleet average reliability well above 99% and fleet average availability above 98%, with very few maintenance stops required.
- **Emissions:** Advanced combustion technology emits four times lower NOx and as much as 150 times lower methane emissions (a greenhouse gas up to 86 times[1] more impactful than carbon dioxide) than reciprocating engines.
- **Fuel flexibility:** Aeroderivative turbines can operate seamlessly running on 100% natural gas to 100% propane, diesel or other fuels without the need for pilot fuels, increasing operational security and lowering fuel costs.
- **Operational flexibility:** In multi-unit configuration, aeroderivative turbines provide excellent operational flexibility. The highest efficiency gains are achieved when the power plant avoids part load operations by starting or stopping units as necessary to follow the grid load during its daily cycles.
- **Lower operations & maintenance costs:** A typical aeroderivative gas turbine requires up to 85 times less maintenance time during its life cycle compared to reciprocating engines. With fewer maintenance events needed, aeroderivative turbines offer much higher availability than reciprocating engines, lowering the cost of capital for available generating equipment. In addition, by reducing maintenance requirements, the operation team can be as much as four times smaller than for an equivalent reciprocating plant.
- **Smaller footprint:** With higher power density and a smaller number of turbines required, an aeroderivative simple cycle plant has a significantly smaller footprint than a reciprocating plant, which can lead to significant capital cost savings.

With over 100 years of experience building more than 65,000 MW of power plants, GE is uniquely qualified to collaborate in developing the new energy security infrastructure. Beyond technical expertise and experience, GE can provide **financing structures**, **long-term services**, **personnel training**, and **remote monitoring** to help assure safe and smooth power plant operation for many years to come.

AERODERIVATIVE TECHNOLOGY OVERVIEW

GE's LM2500* aeroderivative gas turbine is derived from the CF6 family of aviation engines that equipped such aircrafts as the Boeing 747 and 767, the Airbus A330, and the DC-10 and MD-11.



Aviation legacy - proven aeroderivative technology

The LM2500 was launched in 1969 for the propulsion of the US Navy ship GTS Admiral W.M. Callaghan. Since this first application it has continued to develop and evolve "off the wing," more than doubling its power output and increasing its efficiency by incorporating new materials and technologies from the generations of aviation engines that followed.

[1] Based on GWP-20.

Today, **the LM2500 is one of the most successful and well-known aeroderivative gas turbines in the world**, with more than 3,000 units sold for many diverse applications, such as onshore and offshore power generation, gas pipeline compression, marine propulsion, LNG compression, and cogeneration.

This aviation-derived technology affords some unique attributes, such as high reliability and availability, a compact and light footprint, low emissions, fast starts from cold iron , and flexible modes of operation. The aeroderivative turbines are engineered to operate at variable speeds, giving them distinct advantage in solving today's off-frequency grid issues.

In recent years, this technology has found new applications in supporting weak power grids and in firming varying renewable power. The simple nature of solar and wind power requires a system that promotes grid stability throughout the day.

GRID STABILITY & FREQUENCY CONTROL

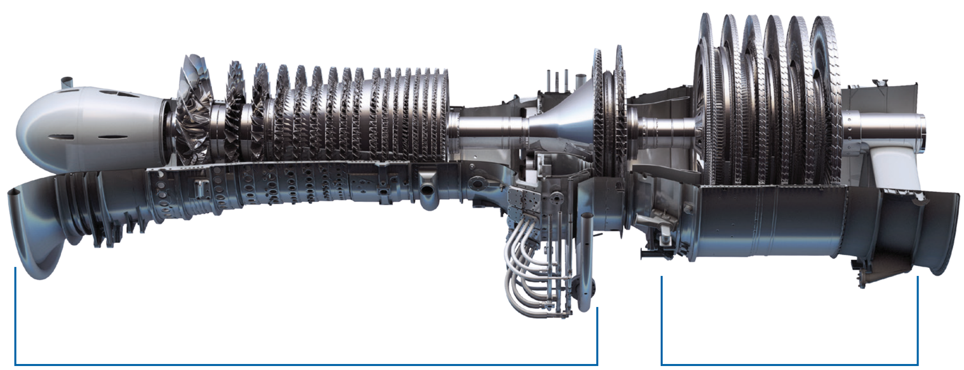
A key challenge to maintaining a stable power grid is **keeping the frequency stable**. Varying frequency makes it harder for generating units to stay in synch with the grid, leading to power grid trips and increasing the potential for blackouts. Additionally, the constant variation in grid frequency significantly increases the maintenance costs of grid-connected units, directly affecting both power generators and consumers.

What's more, varying frequency on the grid makes connecting solar power a lot more difficult. Solar power is generated in direct current (DC) and requires frequency inverters that inject power into an alternating current (AC) grid. This AC power is generated by electronic circuits and must meet a stable frequency (such as 50 Hz) to stay connected. If the grid frequency varies a lot, frequency inverters may trip and batteries connected to the system may burn out.

GE's LM2500 gas turbine generator (GTG) package offers exceptional grid stabilization in support of renewable integration. Key features of the LM2500 package help deliver a power grid that is more **stable**, more **reliable**, and more friendly to the **increased penetration of renewable power** than that provided by either reciprocating gas engines or industrial single shaft gas turbines.

Free spinning power turbine

The LM2500 has a **free spinning power turbine**, meaning that it is a multi-shaft machine and the high-pressure turbine and compressor are not mechanically connected to the low-pressure power turbine which drives the electric generator. Because the power turbine is free spinning, it can accelerate very quickly to compensate for any frequency drops on the grid. The result is a more stable grid and smoother operation for all equipment connected to the grid.



The LM2500+G4 gas turbine

Ramp rates

Ramp rate indicates how fast the turbine can increase power output in response to an instant power demand. Rated at 20 MW per minute from zero to full power, the LM2500's ramp rate is another important feature that helps it maintain grid stability. In fact, LM2500 turbines have demonstrated even higher ramp rates when responding to fast grid changes such as a those caused by the loss of a power line. **The LM2500 responds in milli-seconds** from a frequency change part load, providing extra power within ~100 milliseconds. The response is programmable by adjusting the ramp rate or time in seconds up to the full load capability of the LM2500 GTG package.

The LM2500 running at part load in emissions compliance can provide full load power in approximately 15 to 30 seconds in response to an under-frequency event.

Full load rejection

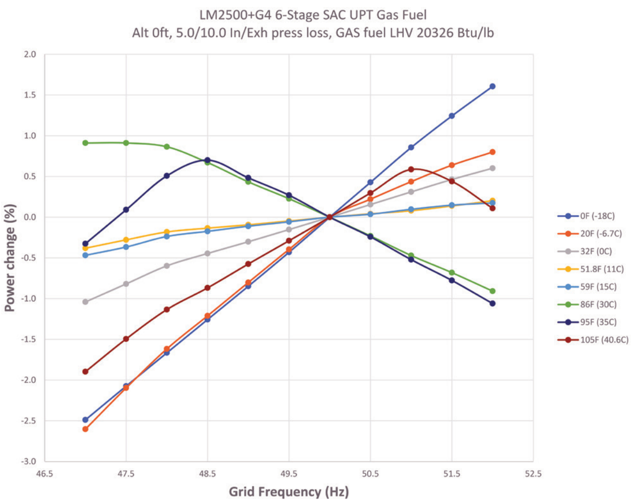
The LM2500 can instantly **reject a full load** by opening the main breaker **without tripping the unit**, remaining at part load or at a minimum load to maintain power to the auxiliaries. The LM2500 will **remain in operation**, ready to quickly provide power back to the grid, while it is common for reciprocating engines to trip under similar scenarios.

Inertia

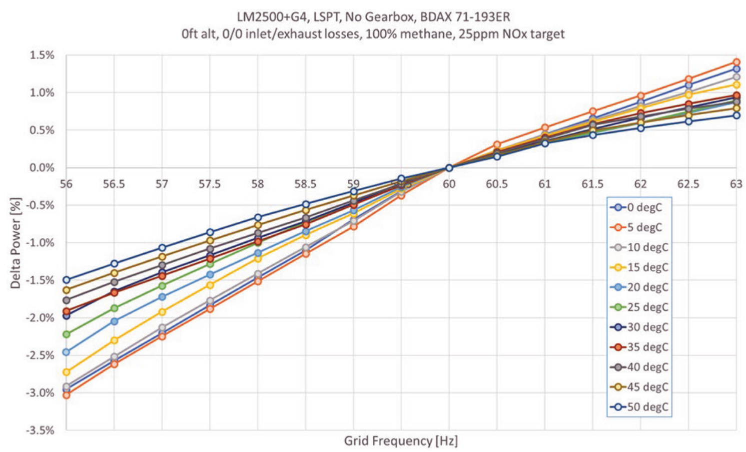
In relatively small grids—those below about 500 MW—**inertia is critical** to maintaining grid stability. Inertia can be thought of as the capacity to maintain speed, and higher inertia systems tend to help stabilize frequency more than low inertia systems. The size of the LM2500's generator—which spins at 3,000 rpm for 50 Hz or 3,600 rpm for 60 Hz—provides high inertia to the system. In fact, due to its size and speed (inertia is a product of mass and the square of the speed of rotation), the LM2500 can provide 10 times the amount of inertia of a reciprocating engine. The LM2500 packages have a minimum inertia of 1.2 kW-sec/kVA with a range capability option to 2.0 kW-sec/kVA per unit.

Operating frequency range

The LM2500 package can operate continuously within a 5% range from nominal frequency. Because there is **no under-frequency trip** function (alarm only) and only a high over-speed trip function to protect the equipment, a wider operation range also is possible. Depending on ambient temperature conditions, GTG packages may increase or decrease power in under-frequency operation down to 46 Hz (for 50 Hz operation) or 56 Hz (for 60 Hz operation). This means that in the event of an under-frequency event on the grid, the units **will remain in operation** and won't worsen the situation by tripping on frequency.



50 Hz Application

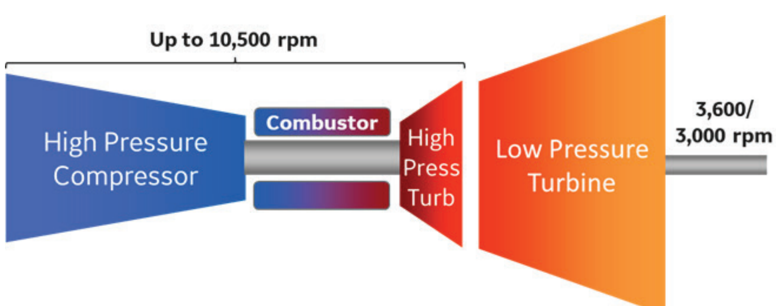


60 Hz Application

Example of a Power x Frequency chart for the LM2500+G4

The LM2500 package is expected to **maintain power** to within 3% of full load between 47 Hz and 50 Hz or between 57 Hz and 60 Hz, across ambient temperature ranges, with no impact on equipment life and no under frequency tripping of the GTG package.

Primary Frequency Control and **Reserve Margin Control** are fully programable with inner and outer dead bands, ramp rates (lag or linear response), and Primary Frequency Reserve Contribution.



LM2500 Shaft configuration

Synchronous condenser

The LM2500 offers an optional feature allowing it to operate as a synchronous condenser. In this mode, the electrical generator remains connected to the grid, providing **inertia** and **voltage/power factor support (via MVAR control)** to the grid without consuming any fuel in the gas turbine. When requested, the packages can seamlessly switch from synchronous condensing to power generation.

The LM2500's **free spinning power turbine** allows it to operate as a synchronous condenser without the use of a clutch between the turbine and the generator, reducing the frequency of maintenance events and associated costs (though run hours in synchronous condenser mode will apply for lube oil replacement).

A synchronous condenser provides reactive power control, either consuming or generating MVAr depending on the grid requirement, to the limits of the generator. Larger generators may be used if higher MVAr is required. The LM2500's synchronous condensing mode lets grid operators regulate voltage to maintain grid stability and avoid any over- or under-voltage tripping within the controlled zone in addition to allowing more active power transmission.

During operation in power generation mode, the AC generator produces real and reactive power to the utility grid and the gas turbine consumes fuel. When operating in synchronous condenser mode, the AC generator supports the grid with voltage provision and export/import reactive power to a desired set point, consumes a small amount of electric auxiliary load and **does not consume any fuel**. With the clutch-less configuration, the power turbine is free-wheeling from AC generator motoring and naturally rotates—via airflow—the high-pressure compressor and turbine shaft to adequate speed.

When required, the operator can select the power generation mode to cycle the gas turbine to start up, light-off and ramp to minimum load and then operate the unit to full power, eliminating the need for any additional spinning reserves, thus lowering installation costs.

Much like the LM2500, GE's LM6000, LM9000 and LMS100 also can operate in synchronous condenser mode to support renewables and boost stability on the grid.

Case Study: Kauai Island Utility

The Kauai Island Utility Cooperative (KIUC) recently converted one of its LM2500 gas turbines to operate as a synchronous condenser.

Kauai—Hawaii's fourth largest island—has one of the highest penetrations of renewable power in any grid in the world, having reached 124% of solar photovoltaic (PV) penetration (installed peak solar capacity divided by the grid peak demand) in 2018. During the day, renewable sources frequently supply 100% of the island's energy needs, with hydro and biomass sources meeting roughly 17% of the demand. Because PV power has no inertia and no capacity to stabilize the grid, the LM2500 provides frequency and voltage support by shutting off its fuel during peak solar hours while remaining synchronized with the grid. At the end of the day, when the sun goes down, the LM2500 is once again fired up to provide active power to the grid.

The LM2500 in Combined Cycle on Kauai

"We've added a synchronous condensing capability to that aeroderivative gas turbine, which is very **critical to our ability to operate at 100% renewables**," explained Brad Rockwell, chief of operations at KIUC (from The Power Hungry Podcast interview, December 2020).

The existing Kapaia Power Station on Kauai originally was commissioned in 2002 and operated continuously in combined cycle mode before the introduction of solar power on the island. Its conversion to also being a synchronous condenser was fundamental to allowing this renewable growth.

In 2010, the LM2500 had only four starts and operated for almost 8,600 hours. In contrast, in 2019, it started 356 times, but was fired for fewer than 7,000 hours, remaining as a synchronous condenser for the remaining time[1].

With the help of the LM2500's synchronous condensing mode operation, which began in February 2019, the plant now has achieved100% renewable energy operation. KIUC is pleased with the final result, and the cost compares very favorably to traditional synchronous condenser options. This new capability helps the LM2500 remains a critical part of the energy mix for many more years to come[1].

"In addition to solar and hydropower, KIUC's steam-injected gas turbine generator at Kapaia Power Station is the first of its kind to be retrofitted to run in synchronous condenser mode," according to the Garden Island newspaper. "This allows the generator, manufactured by General Electric, to **provide inertia**, **fault current**, **voltage support** and **frequency stabilization to the grid without burning fuel**. When power is needed, the turbine can be restarted within five minutes."[2]

While many other power generation technologies are becoming irrelevant and being decommissioned when faced with the increasing penetration of renewables, the LM2500's ability to operate as a synchronous condenser and then provide active power at the flip of a switch means that it will remain critical to stable grid operation—even 20 years after its commissioning.

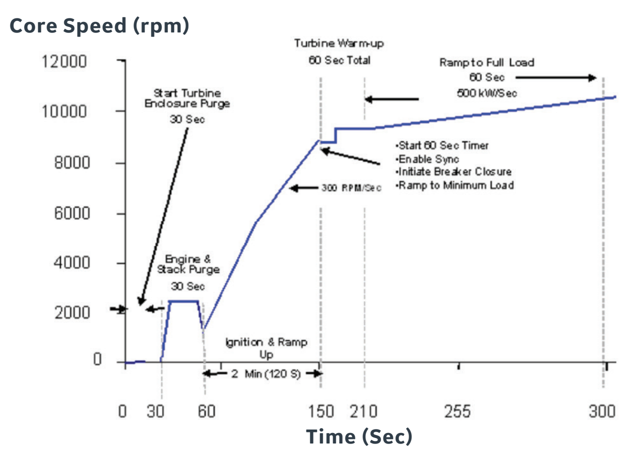
Low voltage ride through (at the GTG MCC)

The LM2500 package can ride through and keep running with minimum to no impact to MW output when the GTG auxiliary system voltage (400/480V) or motor control center (MCC) drops to zero (0) for two seconds. This **continuous operation** requires the fuel supply to have continuous flow and pressure. If the fuel supply drops, power will drop to stay online, producing power as long as fuel pressure and flow is available to minimum load operation. Minimum load operation can be the minimum emissions level down to the auxiliary load power of the GTG package.

FAST STARTS

The LM2500 gas turbine package can start in **five**, **eight** or **ten minutes**, **from cold iron to full load**. Additionally, when operating as a spinning reserve, the unit's primary frequency response equivalent ramp rate from minimum emission compliant load (MECL) to full power is between 15 and 30 seconds, depending on control parameters.

An important feature of an aeroderivative power plant is that the **various units may start up simultaneously**, considerably reducing total plant start-up time. This is unlike reciprocating gas engine plants where each engine typically starts up sequentially, given compressed air restrictions, resulting in a very long start-up period for plants with almost 28 units.



Typical start curves for an LM2500 in simple cycle

While **reciprocating gas engines** are stated to start in only five minutes, in reality they require jacket water above 60°C and lube oil temperature above 70°C in order to do so. This leads to a high parasitic load consumption, as **electrical heaters** must be maintained at all times during hot stand-by mode. Typically, a reciprocating gas engine consumes more than 100 kW of parasitic loads per unit while in hot stand-by mode. This can represent as much as $130,000 USD per year just to keep one unit hot. In a power plant with 30 units, the total heating cost can easily reach **about $4 million USD per year of parasitic costs**. When operating with heavy fuel oil (HFO), these costs are even higher.

[1] KIUC presentation at WTUI – Western Turbine Users Inc.

[2] The Garden Island Newspaper, December 18, 2019.

[3] Generator Lube oil pump must be running to maintain ready to start condition for 60Hz application.

[3] Simple Cycle application, No SCR or HRSG/Boiler.

MULTIPLE STARTS AND STOPS

Based on technology derived from the aviation industry, the LM2500 can perform daily starts and stops **without impacting its maintenance cycles or costs**, unlike a typical industrial gas turbine.

In grids with high renewable power penetration, this ability to shut down and start up units daily is of tremendous value. It allows a power plant to cycle in power output to follow the demand from the grid and compensate for variable renewable generation.

Units that are shut down when the load is low can continue operating as synchronous condensers (see item 2.1.6). In this mode, they can provide inertia and voltage control to the grid without using any fuel and be ready to start as required when grid demand grows.

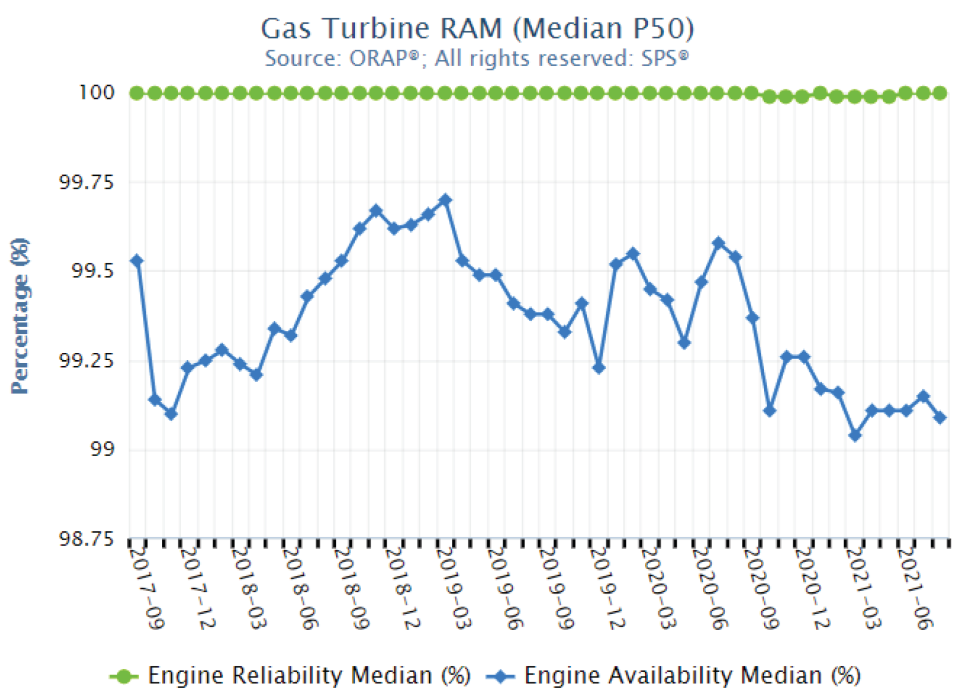
This is why aeroderivative gas turbines have been used extensively around the world as peaking units, **ready to start at any moment** and with no maintenance impact for a daily cold start.

RELIABILITY & AVAILABILITY

Reliability is essential in the aviation world. The LM2500 aeroderivative gas turbine has inherited this trait, demonstrating a fleet average **reliability above 99%**. What's more, at least half the fleet operates at 100% reliability. This exceptional reliability is also a key feature for small grids that rely on the optimal performance of each generator.

Availability is another key aspect of the LM2500 technology. While higher reliability translates to a reduction in unscheduled maintenance, higher availability focuses on reducing scheduled downtime. Another legacy of the aviation industry is the ability to quickly swap out engines during a major overhaul. After replacing a unit with one that has already had maintenance, the plant can resume operation in as little as two days, compared to more than 20 days of downtime for other technologies.

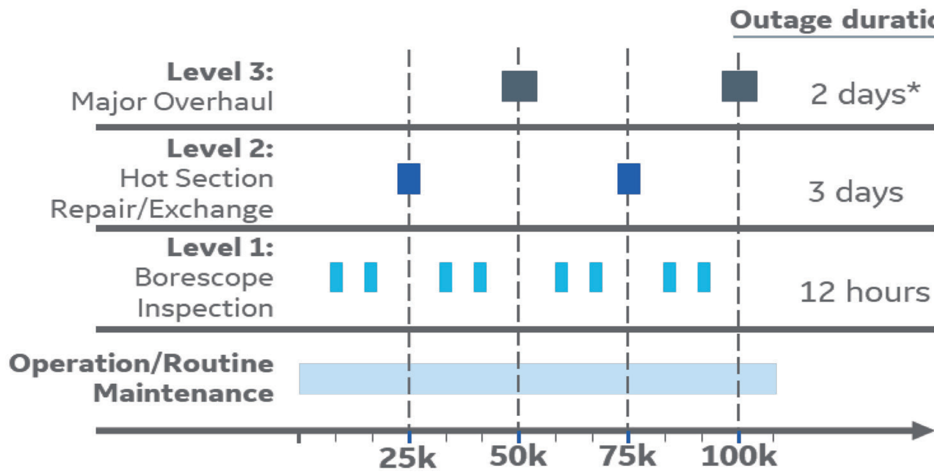
Fleet data collected by the independent, third-party, ORAP shows that LM2500 units have averaged reliability of more than 99% and availability higher than 98% over a 20-year period. The latest four-year data as reported by ORAP is shown in the following figure.



ORAP fleet reliability and availability data

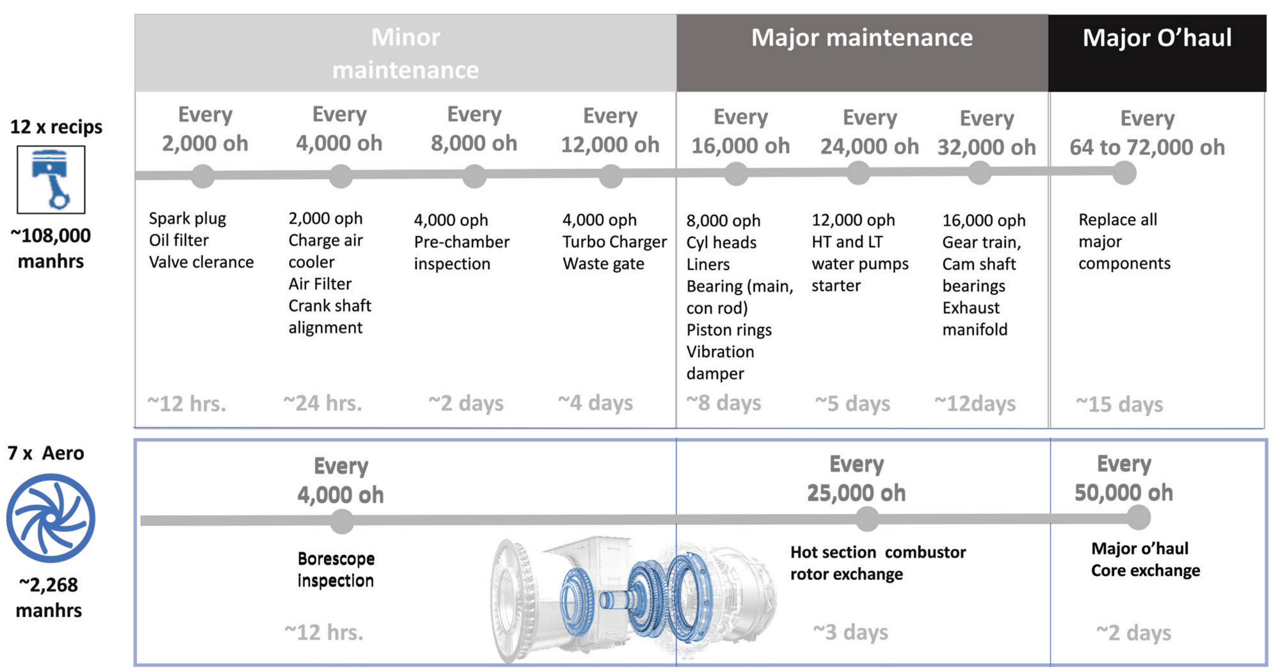
The number of maintenance intervals also is reduced compared to reciprocating technologies. An LM2500 typically only has to undergo an inspection (approximately 12 hours in duration) for every six months of operation, a hot section maintenance at 25,000 hours of operation, and a major overhaul at 50,000 hours. Because no further scheduled maintenance events are required, unit availability is increased and the corresponding need for operation and maintenance personnel also is substantially reduced (see the following figure).

In **10 years of continuous operation, only 18 days** of scheduled maintenance is required.



Operating hours vs. planned maintenance type/duration

Meanwhile, alternative technologies such as reciprocating engines require planned stoppages after every 1,000 to 2,000 operating hours and events that follow can lead to downtimes of 15 hours to 20 days each. The following chart shows the number of maintenance events required for each unit and the estimated maintenance hours for aeroderivative turbines versus reciprocating engines.



Reciprocating engines vs. aeroderivative maintenance events

Due to higher downtime, lower reliability, and lower meantime between failure (MTBF), a reciprocating engine-based plant typically needs one standby unit for every five to six units in operation. This leads to higher Capex, greater operation and maintenance costs, and higher parts inventory.

EMISSIONS

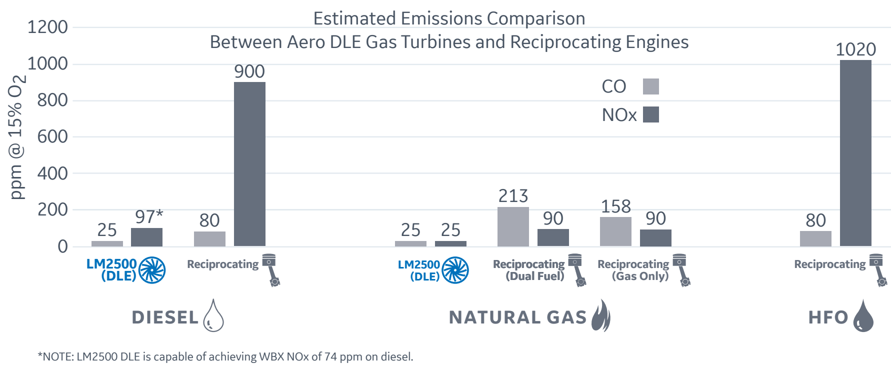
Because land-based power generation is subject to much more stringent emissions requirements than airborne engines, combustion technology has developed significantly "off the wing."

World Bank establishes 51 mg/Nm^3 of NOx emissions (@15% O_2) in its Environmental Health and Safety Guidelines for gas turbine power plants running on natural gas, or 152 mg/Nm^3 when running on other fuels, such as diesel or propane.

Dual fuel reciprocating engines, on the other hand, can emit up to 400 mg/Nm^3, according to the same document, or up to 2000 mg/Nm^3 when running on liquid fuels.

According to the EPA, "breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2.

"NO_2, along with other NOx, reacts with other chemicals in the air to form both particulate matter and ozone. These substances are also harmful when inhaled due to their effects on the respiratory system."



Estimated emissions comparison - aeroderivative vs. reciprocating engines

Another important emission to be noted is **methane**. When burning natural gas, a small part of methane may be emitted unburned from the engine. However, methane emissions must be monitored closely, because the global warming potential (GWP) over 20 years of a single molecule of methane (GWP20) may be 86 times higher than that of CO_2, according to the Intergovernmental Panel on Climate Change (IPCC). The EPA defines the methane emission factor in gas turbines to be 0.0086 lb/MMBTU of fuel only, while reciprocating gas engines may emit up to 1.25 lb/MMBTU, a number **145 times larger than gas turbines**, greatly contributing to greenhouse gas (GHG) emissions from power generation.

For a 500 MW power plant, a switch from reciprocating engines burning natural gas to aeroderivative gas turbines in simple cycle will decrease GHG emissions by 37%. This represents taking more than **100,000 cars off the roads** in terms of GHG emissions, considering baseload operation.

200 MW Power Plant		Reciprocating Engines on NG	Aeroderivative Turbines on NG
CO_2 emissions (1)	kg/MMBTU of fuel	49.9	49.9
CH_4 emissions (1)	g/MMBTU of fuel	567.0	3.9
Efficiency GWP20 of CH_4 (2) Total GHG	 86 kg/MWh	46% 732	37% 463
GHG for 200 MW Change in GHG Equiv. number of cars (3)	t CO_2equiv./yr t CO_2equiv./yr	1,282,185	 811,616 -37% -102,000

(1) EPA Air Emissions Factors, AP 42, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources
(2) IPCC Report Climate Change 2013: The Physical Science Basis, Chapter 8, Table 8.7
(3) Based on EPA emissions for average car: 4.6 tCO_2/yr.

Estimated GHG emissions comparison between aeroderivative vs. reciprocating engines

NOTE: Sometimes GWP20 used as alternative to GWP100. It is based on the energy absorbed over 20 years and it prioritizes gases with shorter life-span. It would be meaningful to use GWP20 instead of GWP100 for following reasons: Residence time for CH4 is ~10 years; Typical project life span is 20 – 25 years, and; Climate change impact is more near term.

FUEL FLEXIBILITY

Being able to operate on a range of fuels helps to deliver **energy security** if the natural gas supply is cut for any reason. The LM2500 can seamlessly change from lean treated **natural gas** to rich **offshore gas**, **propane** or **diesel** without shutting down and with little or no reduction in output or efficiency. The units even can be adapted to operate with **bioethanol** or **naphtha**, further increasing energy security.

Another advantage for aeroderivative gas turbines is that they can operate on **hydrogen (H_2)** blend, which does not provide any carbon emissions when combusted. This includes both new gas turbines and existing units, which can be converted to operation on a high H_2 fuel.

Additionally, the units are truly dual fuel, able to go from 100% natural gas, for instance, to 100% propane, without requiring any pilot fuel that can substantially increase the price of electricity. Dual fuel reciprocating engines, for instance, require about 5% diesel when operating on gas, increasing both costs and emissions.

LUBE OIL CONSUMPTION

Aeroderivative turbines consume significantly less lubricating oil than reciprocating engines. An LM2500 aeroderivative turbine typically consumes about 200 times less lube oil than a reciprocating engine (approximately 2 ml/MWh for the LM2500 compared to up to 400 ml/MWh for a reciprocating engine).

Lube oil alone can represent a **savings of more than $2 million USD per year** for a 200 MW baseload aeroderivative turbine power plant compared to a reciprocating engine plant (lube oil considered at $3 USD/L).

For a standby plant, the lube oil consumption may not have a big impact; however, the oil must be replaced intermittently due to limited shelf life.

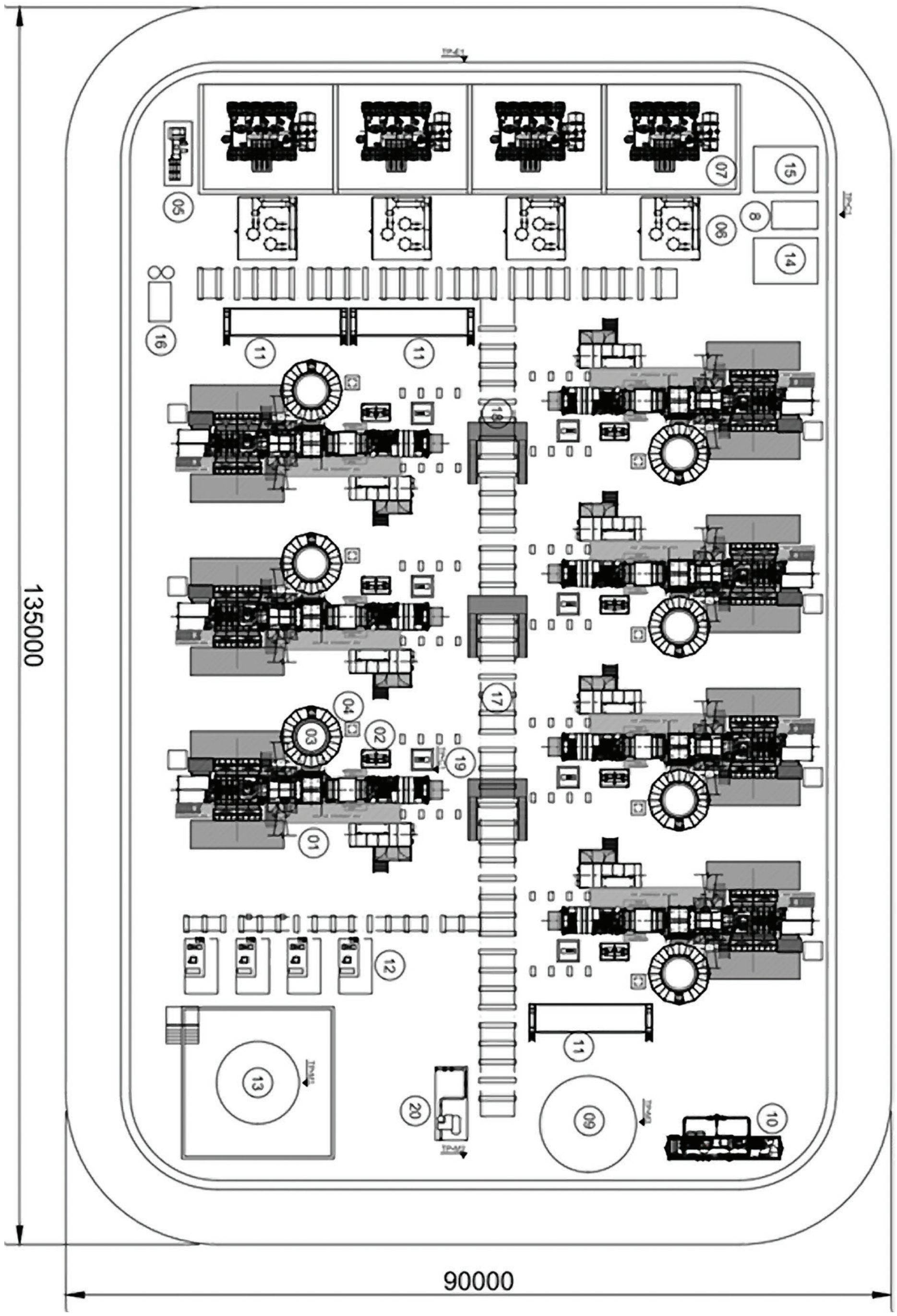
OPERATIONS & MAINTENANCE STAFF

The following table shows the estimated staffing requirement for a typical 200 MWe simple cycle aeroderivative gas turbine-based power plant, assuming all the units are co-located. An aeroderivative turbine plant has significantly reduced manpower needs—due to fewer units and substantially fewer routine maintenance activities—compared to a reciprocating engine-based plant. This means much lower annual expenditures for the O&M staff. Typically, a similarly large power plant based on reciprocating engines would be installed in four different power houses with independent manpower needed to operate each powerhouse.

Title	200 MWe Co-located Aeroderivative Power Plant
Plant Manager	1
Maintenance Manager	1
Control Room Operators	7
Electrical Technicians	2
Instrument and Controls Technicians	1
Mechanical Technicians	2
Administrative Manager	1
TOTAL	**15**

POWER DENSITY

Another characteristic of an aeroderivative power plant is its compact footprint. The following layout shows a suggested configuration for a plant with 7 units, totaling 215 MW in hot day operation (~259 MW ISO) and occupying an area only 135 x 90 meters, or 3 acres.

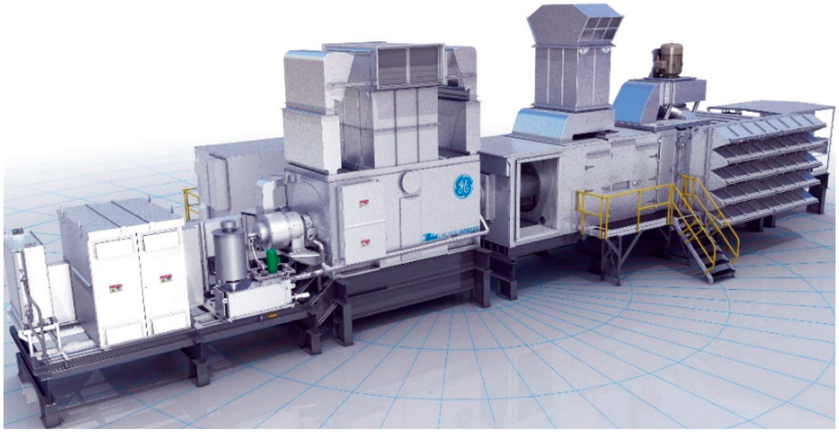


A 259 MW ISO plant occupying 3 acres

By increasing output with inlet chilling on hot days, the number of units can be further reduced—to about 6—while maintaining the same 215 MW total output (not shown in the above configuration).

LM2500XPRESS – ENGINEERED FOR SPEED AND SIMPLICITY

GE's most experienced and technologically advanced aeroderivative gas turbine, the LM2500, has been integrated into an innovative package configuration ideally suited for a variety of applications, ranging from baseload to peaking applications, simple cycle, combined cycle, and cogeneration or combined heat and power (CHP) configurations.



LM2500XPRESS Package

Delivering up to 37 MW with 39% simple cycle efficiency, the LM2500XPRESS GTG package offers an innovative, modularized concept that translate to significant operational and economic advantages:

- Offers dry low emission (DLE) with gas or dual fuel options.
- Delivered in 10 simplified modules, with up to 95% of the assembly completed in the factory, for easy on-site installation.
- Has faster site installation with minimal mechanical and electrical interconnects and quick electrical disconnects.
- No site flushing of module systems completed at factory —25% fewer interconnects than traditional GTG installations.
- Meets CE/ATEX and UL/FM Class certification requirements.
- Rated at 85 dBA Average Noise/SPL.

LIFE-CYCLE SUPPORT

LONG-TERM SERVICE AGREEMENTS

A long-term service agreement, like a **contractual service agreement (CSA)** or a **multi-year maintenance program (MMP)**, provides better access to the technology needed to keep a gas power plant relevant for years to come. As the world's largest supplier of gas turbine technology, with the world's largest installed base, GE is ready to help our customers meet the challenges of tomorrow—today.

An MMP gives the power plant the flexibility to determine maintenance scope while relying on GE to help to deliver high-quality gas turbine parts and services at preferential conditions, reducing administrative efforts and simplifying planning.

Services offerings to meet your needs

	Framework	MMP/ Planned MYA	Full MYA
Field service engineering and parts supply	x	x	x
Pre-negotiated terms and conditions	x	x	x
Remote monitoring and diagnostics	x	x	x
Major maintenance scope and cost risk		o	x
Major maintenance interval risk		o	x
Service bulletin coverage		o	x
Outage related guarantees		o	x
Unplanned maintenance risk			x
Performance guarantees and optimization			o
Integrated lease and engine exchange			o

x Standard o Optional

Build the package that is right for you

Lease and engine exchange program

Membership in GE's turbine exchange or lease program also is available. The program guarantees delivery of a complete engine to your site in less than three days. The engine can be installed and operating at full load within hours. Unlike heavy reciprocating engines weighing hundreds of tons, light high-alloy aeroderivative gas turbine engines and components can be flown in and out of the power plant in literally hours in case of emergencies.

Lease membership to support planned & unplanned outages

Obtain short-term use of gas turbines, gas generators or power turbines as an alternative or supplement to spare engines during outages:

- Provides spare engine support without a major investment.
- Pulls from the largest LM fleet pool with more than 90 engines ready to be deployed.
- Helps to reduce annual fees and usage rates.
- Dramatically reduces downtime from as much as 90 days to just six days.

Backup lease membership stands in for the spare engine:

- Obtain the use of lease assets as a backup to their spare engines.
- Get cost-effective "double insurance" for asset availability.

Long-term lease to improve fleet operations

Obtain long-term use of lease assets with an option to capture the asset's useful life at end of the lease:

- Attain assets without outlaying essential cash.
- Receive lease term flexibility to match power purchase agreements.
- Shift capital expenditure to operation expenses.
- Ideal for a long planning horizon.

Engine exchange

Achieve the highest asset availability and lowest outage variability (only one outage required):

- Exchange plant assets for new or overhauled engines—with full-service bulletin compliance and covered by full GE warranty.
- Get a true fixed price with no scope creep due to part fallout and no lease fees.
- Receive a buyback value offer on exchanged units.

Remote monitoring & diagnostics

Every day, GE collects more than 30,000 operating hours of data from more than 1,600 globally deployed power generation assets, supplementing a 40 terabyte database representing more than 100 million fleet operating hours.

At GE's Monitoring & Diagnostics (M&D) Center in Atlanta, Georgia, USA, a team of more than 50 M&D engineers analyzes more than 35,000 operational alarms per year, assisting customers in enhancing their asset reliability and performance 24/7, 365 days a year.

Additional regional support is provided from locations in Scotland, France and India. Using a combination of off-the-shelf and custom analytic tools, the team diagnoses problems ranging from failed sensors to gas turbine compressor damage. Drawing on the experience of hundreds of thousands of alarms resolved, the team has developed dozens of physics-based proprietary algorithms that provide early warning of more than 60 different failure mechanisms.

The wealth of physical understanding combined with the intelligent application of statistical methods has enabled the team to continually improve the algorithms, thereby increasing the probability of detection while reducing false alarms.

Decisions through data

M&D services from GE provide a number of options for accessing the data that's important to customers, along with a selection of decision support tools built on OEM knowledge, engineering know-how, and depth of fleet experience.

At the customer's site, GE's **On-Site Monitor (OSM)** tool automatically collects and processes data through advanced algorithms—trending against fleet-wide historical data—to determine fleet health, develop prognostics and helps to deliver information to customers through several reporting options.

GE's monthly **Operational Assessments Report** provides key asset health and operational metrics to help customers manage asset maintenance and plan for outage scope.

Operation & maintenance support

GE can provide customizable operation and maintenance (O&M) power plant services options. Whether the customer is seeking advisory services to enhance its operation or looking for a full-service operator to perform all the daily activities associated with operating its site, GE can create an operational collaboration and planned gas plant maintenance contract with solutions to meet the customer's business goals. A combination of an O&M collaboration with CSA or MMP programs, can help increase a gas plant's productivity, enhance profitability, and maintain the flexibility to adapt the operation over time as organizational needs and goals evolve. Best of all, customers gain long-term financial predictability.

With more than 1 million MW installed in more than 120 countries, GE's MYAs are available wherever they are needed.

Resident engineer support

To support the local O&M team to smoothly take over power plant operations, GE can base a technical advisor on the customer's site for three to six months, depending on the contractual arrangement.

The roles and responsibilities for the resident technical advisor are:

- Provides on-site training for maintenance and operational staff and assists in the establishment of robust routine maintenance practices.
- Evaluates equipment performance and recommends adjustments as required.
- Recommends routine maintenance activities and supervises the work to be completed.
- Evaluates planned and unplanned outages and, to the extent consistent with individual training and site conditions, executes troubleshooting and corrective actions.
- Reviews equipment performance and suggests improvement as required.
- Works with the contracting party to improve overall equipment reliability, availability, and start-ups.
- Works with the customer to define communication protocols and improve working schedules to accommodate the site's specific dispatch needs.

Training programs

Power plant personnel with hands-on experience using the latest tools and technologies are vital to maintaining plant availability, reliability and flexibility. That's why GE offers comprehensive, flexible training solutions for effective power plant operation in today's intensely competitive power industry.

Constructed to develop expertise through a variety of flexible methods throughout the plant's lifecycle, GE's Gas Power **Customer Training courses** cover more than 200 topics. These high-value courses are built using site-specific manuals, configurations, drawings and software (as available) and may contain a mix of classroom learning, site walkdowns and hands-on training. Delivered over a 3-week period, the training includes familiarization, operations and controls courses and is delivered either at one of GE's global learning centers or at the customer's site—in the language of the customer's choice and on a schedule that works for the customer.

GE also offers cost-effective online courses applicable to a broad range of personnel—anytime, anywhere, and at their own pace. Each of the 25 available English-language courses ranges in duration from one to several hours and can be started and stopped at the student's discretion.

Typical Course Content:

Aero Package Operation/Familiarization

- Introduces the basic skills and knowledge required to support proper operation of the gas turbine and its associated systems.
- Focuses on operator responsibilities such as start-up, loading, and monitoring during operation as well as interpretation of fault annunciation for suitable remediation.

Package Maintenance

- Introduces operations and maintenance personnel to the routine preventative maintenance procedures and minor mechanical maintenance.
- Covers basic troubleshooting and summarizes the inspections required for minor gas turbine generator mechanical maintenance.
- Encourages operation and maintenance personnel to attend together to develop a working relationship regarding maintenance requirements.
- Includes detailed Level 1 maintenance work packages and familiarization with the O&M Manual.

CONCLUSION

Aeroderivative turbines offer flexibility, modularity and scalability comparable to any alternate technologies without compromising reliability, availability and environmental goals

PROVEN TECHNOLOGY
3,000+ LM2500 aeroderivative gas turbines deployed, with ~100 million operational hours of experience

EXCEPTIONAL RELIABILITY AND AVAILABILITY
One of the most reliable distributed power units available due to its aviation legacy.

FAST START AND CYCLIC TOLERANCE
Ability to start and achieve full load within 5 minutes from cold iron. No impact of daily start/stop on maintenance.

HIGH-QUALITY POWER
Better grid stability, frequency control, reliability and synchronous condensing capability.

SEAMLESS RENEWABLE INTEGRATION
Greater renewable penetration with enhanced grid stability.

FUEL FLEXIBILITY
Greater energy security and lower costs with fuel-flexible operation on natural gas, propane, diesel or many other fuels. Pilot fuel injection not needed in dual fuel mode.

REDUCED EMISSIONS
145X lower methane, 4X lower NOx, 10X lower CO, and 6X lower PM and VOC emissions than reciprocating engines operating on natural gas—without the need for aftertreatment

SCALABLE, RELIABLE POWER
Modular concept for easy addition of blocks of power as demand increases.

LOWER COST OF ENERGY
High efficiencies, low maintenance costs and high availability best suited for baseload and high fuel cost applications.

FINANCING OPTIONS
Flexible financing solutions are available to help meet specific customer needs.

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