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Application of lean-burn gas generator sets in standby service

> White paper

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Standby generator sets have been traditionally diesel engine driven and in limited cases stoichiometric (rich burn) natural gas or propane. These are popular choices because they provide a high level of performance and in the case of diesel especially, provide a high ratio of energy per unit volume of fuel stored at site.

More recently there is an increased interest in utilizing generator sets fueled by natural gas or renewable gaseous fuels. This trend is driven by a number of factors such as low exhaust emissions, higher efficiency, reduced carbon footprint, a desire to avoid diesel fuel storage issues, and potentially the use of renewable fuels.

Within Cummins Power Generation's line of products there is a range of reciprocating gaseous fueled generator sets that utilize lean-burn technology. lean-burn technology incorporates high air to fuel ratio and excess oxygen to gain overall output efficiency at greatly reduced NOx emissions.[1] These efficiency levels often exceed those of equivalent sized diesel products. Exhaust emissions are significantly lower than stoichiometric gas engines and greatly reduced from a diesel.

This paper addresses issues associated with lean-burn natural gas (LBNG) generator sets applied in standby service applications.

Typical standby performance and ratings

A generator set in standby service as compared to other service such as peak Shaving or prime Power has unique requirements for starting and performance. Emergency codes such as NFPA 110 Standard for Emergency and standby Power Systems® and CSA 282 Emergency Electrical Power Supply for Buildings have requirements for quick starting, 10 seconds for defined Emergency and some legally required systems. Certain other defined systems allow longer times to start and be ready to accept load, in some cases no time provisions are specified.

Load step acceptance capability is usually a critical factor in standby service. Switching from normal to emergency power sources through the use of large transfer switches high in the system usually result in single load steps that are a high percentage of the generator set rating. The generator set is not only expected to pick up this load step but to do it with relatively small voltage and frequency disturbance and to return to stability in a relatively short time. The practice of using smaller switching lower in the system mitigates this issue by dividing and sequencing load steps.

Another difference between standby and other service is typically the rating of a standby rated generator set is at or near its maximum capability in terms of engine horsepower and alternator kVA. One reason for this is to make full used of the hardware capability, providing adequate power in the smallest, lowest cost package available. The application designer must take this into account when considering total load and load step requirements.

[1] Reference Cummins Power Generation: Power topic #7009, Lean-burn engine technology increases efficiency, reduces NOx emissions. Keith Packham.

A generator set in prime duty will normally have some reserve capacity, at least 10 percent, to allow for momentary overloads. When applied in parallel to a grid this margin allows for variations in load and grid enhancing parallel operation. Also reserve capacity of the engine HP and alternator kVA will provide extended life for high hour usage. This can become important in cost mitigation as discussed later in this article.

Lean-burn NG performance

Starting and power availability

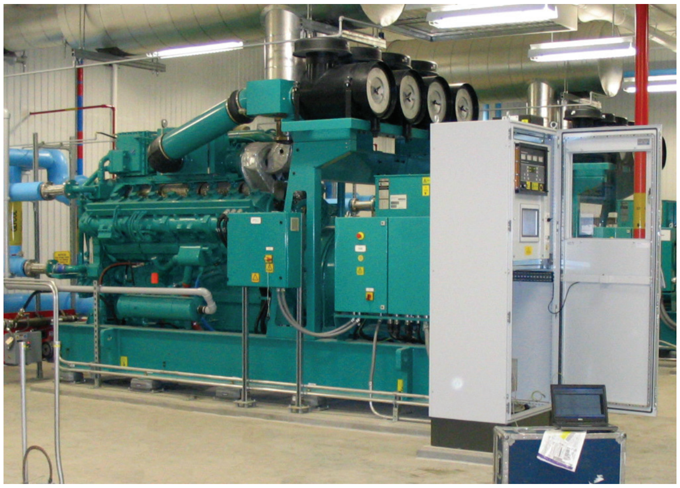

FIGURE 1 – 1400 kW LBNG standby generator set in a water treatment facility.

Lean-burn combustion technology has many facets but is essentially having a higher air-to-fuel ratio in the combustion chamber (more air than there is fuel to consume it), which results in more complete combustion of the gaseous fuel and cooler combustion temperatures. Through utilization of lean-burn technology these products achieve high efficiency and low emissions. As with any engineering endeavor something is traded for the improved efficiency and emissions, that trade-off is the quickest starting (as compared to a diesel for example) and high percentage load step capability.

Some LBNG generator sets, with other site considerations can be ready to provide power in as little as 20-30 seconds from start command. Other models require pre-lube cycles and warm-up and so require time on the order of minutes. If this range of time between outage and backup power availability is acceptable these generator sets are well suited to the task. For more time critical loads, UPS equipment is an option to provide uninterrupted power with the utility power supply to the UPS backed up by the generator.

Load pickup and stability

A diesel powered generator set is generally fast responding and able to pick up large load steps with reasonable voltage and frequency disturbance. Often a diesel can pick up 100 percent of rated power in a single step and recover quickly. The load step capability of a lean-burn gaseous generator set is normally in a range of 10-75 percent. The difference in response is a result of the differences in fuel delivery systems of the two engine technologies. The wide range of 30-75 percent is due to the various system technologies within the lean-burn spectrum.

Within the range of lean-burn technology generator sets there are two types, one optimized for tolerance to temperature, altitude and load steps, the other optimized for efficiency. The later uses specific technology variations in the area of combustion and for example a single large turbo charger as apposed to multiple turbo chargers. These higher efficiency models are designed primarily for continuous duty operation parallel to a utility grid and pose unique challenges when operating in Island mode (not connected to a utility grid).

The greatest trade-off of these single turbo models is the ability to pick up a large load in a single step. Where Cummins multi-turbo units can pick up a load step of 50-75 percent of rating with reasonable performance, single turbo, ultra high efficiency models are limited to 10-25 percent of rated. This does not necessarily mean they cannot be applied operating in island mode rather that special attention must be paid to the load step size and sequence. In island operation these design characteristics can also result in slightly higher variation at steady state. If the load steps and surge requirements can be managed within the capability levels, and the steady state performance is suitable to the application then acceptable performance is achievable.

Regarding rated power note that lean-burn generator sets are designed for Continuous duty, normally in parallel to a grid or other generator sets. There is no special rating for standby service and no overload capability. So as with a standby rated generator set, the application designer must take this into account when considering total load and load step requirements. As with all standby rated designs, the best practice is to start large loads first and then add smaller loads.

Accessory equipment requirements

Starting and readiness

Lean-burn generator sets were originally designed for continuous duty and very long life. For this reason care is taken to avoid issues that shorten engine life. These include a pre-lube cycle either prior to each start or on a timed schedule. Also heavier straight-weight oils are used. In addition the engines will operate at idle speed until oil and coolant reach suitable temperature. For these reasons total starting times, the time between issuing a start signal and being ready to load, can be extended considerably compared to standby duty generator sets.

To quicken the starting and load pickup capability coolant heaters are standard as with a standby generator set. A helpful addition is an optional external oil heater. Start times are reduced with a properly sized and circulating type oil heater. Maintaining the generator set room temperature above 60ºF (15ºC) degrees will also ease starting and run up.

FIGURE 2 – Optional oil heater may be required to maintain the sump oil temperature at a level to facilitate quick start and run up.

Certain generator set models require the engine air inlet temperature (combustion air) to remain within a range, minimum as well as maximum temperature. In cooler climates this may require the room ambient be controlled within a specified range avoiding pulling the cold outside air directly into the engine intake. This can be easily accomplished in room ventilation design with variable speed fans and if necessary thermally controlled louvers.

Switching and connection

In any on-site generation system a method of switching loads from utility power onto generator sets and back is required. In a standby application when utility power fails there is a power interruption before the generator set(s) is (are) started and connected to the loads. When the utility returns there are methods to switch the loads back to the utility power with or without another interruption in power. For testing of the system the same switching method is used and so the interruption of power is a consideration. This leads to understanding of three basic switching methods and their characteristics.

1. If an open transition switching method is used (an open transition ATS or equivalent circuit breaker function) there will be an interruption in power in all switching circumstances.
2. If closed transition fast transfer switching is used (i.e. a closed transition ATS or equivalent circuit breaker function) an interruption can be avoided when switching between live sources but a disturbance will be seen. The amount of disturbance, both voltage and frequency, will be determined by the loads and the source impedance. When switching onto the generator set the load amounts must be managed within the load acceptance limitation of the generator set as discussed earlier. The larger the load step the larger the disturbance that will be experienced.
3. To achieve no interruptions and no disturbance (seamless transition) requires soft loading closed transfer which must be accomplished using paralleling equipment and a load ramp function. If this method is used the transition between two live sources will be essentially undetectable in the facility. This method is also highly desirable if the system is also planned to be used for peak shaving.

In conjunction with the switching method consideration of the amount of load switched is critical as described in the previous section. If open or closed transition fast transfer methods are used the total load to be switched cannot exceed the generator set's load step capability. If this is the case then the loads must be sequenced by using multiple switches, time delay starts, manual starting, or another method of sequencing the addition of the loads onto the generator set.

Cummins Power Generation has equipment offerings for any of these switching methods. The lean-burn generator set controls include paralleling and ramp loading functions as standard, the only other required equipment is a paralleling circuit breaker.

Cost mitigation through peak shaving or CHP

As a general rule diesel standby generator sets are relatively inexpensive protection against utility power outages. Upgrading to high efficiency, low emissions, lean-burn gas generator sets will cost moderately more. Higher performing systems of switching and energy recovery alternatives can add additional costs but can also provide additional benefit. In any of these circumstances there are methods of cost mitigation that should not be overlooked.

First of all from an operational perspective it costs about 60 percent less to generate electricity from natural gas than to burn #2 diesel fuel (based on natural gas at $6 per mmBTU and #2 diesel at $2 per gallon).

One method is peak shaving or interruptible service contracts. peak shaving is somewhat self explanatory and is carrying the peak load of a facility using the generator set. This is viable if peak demand electric rates are such that there is a significant savings opportunity by reducing or "shaving" the peak load demand of the facility. Interruptible service is a commitment to remove load from the utility when the utility needs to reduce their overall demand, typically during peak hours. In exchange for the ability to "remove" a facility load from the grid and power with on-site generation the facility gets compensation usually in the form of reduced electric rates.

FIGURE 3 – Switchgear required for single generator set utility paralleling operation – peak shaving.

A second method for cost mitigation of a standby system is to install a CHP, combined heat and power, system. Recovering heat from generator set cooling circuits and exhaust, and using that heat to substitute for other energy use can save considerable money. The energy efficiency of a system such as this can reach as high as 90 percent where grid generated electricity is in the range of 25-30 percent efficient. There is a higher initial investment but the return can be sufficient to pay for the system in whole or in part in a short time.[2]

Alternative (renewable) fuels use.

There are lean-burn generator set models capable of operating on waste and renewable fuels from sources such as landfills, digesters, coal and organic gasification systems, and more. Generally these fuel sources are not applicable to standby applications.

FIGURE 4 – Custom packaged LBNG CHP system.

Realistically, issues of fuel availability or storage capability present potential limitations to the use of such fuels for defined emergency or legally required systems and possibly for optional systems as well. If renewable fuels are available it is desirable to operate the generator set continuously for extended time on the renewable fuel thus the renewable or waste product energy displaces use of other (non-renewable) energy sources. The applicability for standby service is determined by site requirements or local and national regulations regarding these systems. If conditions are such to satisfy site requirements and regulations applying to the particular system then the application can be viable. The generator set's suitability can then be evaluated based on the operational criteria outlined in this paper. Consult a Cummins Power Generation representative for details of alternative or renewable fuel use.[3]

[2] Reference Cummins Power Generation: Power topic #7018 Evaluating cogeneration for your facility..., Joel Puncochar.

[3] Reference Cummins Power Generation: Power topic #6015 The case for waste to energy: Utilizing low-BTU reciprocating gas engine generators Keith Packham.

About the author

Timothy A. Loehlein is a graduate of the University of Minnesota with a Bachelor of Electrical Engineering and a PE in Minnesota. Tim has been a Cummins Power Generation employee since 1976 in positions as Application Engineer, Design Engineer, Technical Project Leader and Manager. His current position is a Technical Specialist—Electrical in application engineering for Cummins Energy Solutions Business, supporting applications in nonstandard gaseous fuels, combined heat and power (CHP) and peak shaving.

Conclusion

The application of lean-burn gaseous fueled generator sets in standby service is a very viable alternative to diesel or stoichiometric gas powered generator sets. The advantages are efficiency, very low emissions, reduced carbon footprint, and potentially the use of alternative and renewable fuels. In addition the issues of diesel fuel storage, delivery and fuel maintenance are eliminated.

The critical elements of successfully applying a LBNG generator set to standby service are equipment startup and load pickup capabilities. Design trade-offs for LBNG generator sets create limitation in start time capability critical to some applications. Certain actions can be taken in installation design to mitigate this issue. Load pickup needs must be evaluated thorough analysis of the loads, load steps and sequence with respect to the generator set capability and site requirements.

As with any standby power application UPSs should be used for time critical loads that cannot tolerate any power interruption. Any loads that legally require generator set back up and require a fast startup (in the area of 10 seconds) should be on a diesel generator set, while those that can tolerate a longer interruption in power can be backed up by a LBNG generator set.

Generator set prototype test summaries, PTS statements, and specification sheets are available from Cummins Power Generation, and provide generator set performance information. Accessory equipment or site design requirements may be needed to meet the application requirements but these are straightforward and inexpensive additions. The Energy Solutions Business of Cummins Power Generation is available to assist with analysis, recommendations and any additional application assistance required.

For additional technical support, please contact your local Cummins Power Generation distributor. To locate your distributor, visit www.cumminspower.com.

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