Gas Generator Set
PERFORMANCE CHARACTERISTICS

AUTHOR
CLAY HARDENBURGER
Senior Staff Applications Engineer

Kohler Co.
Power Systems Division

INTRODUCTION

Over the past 15 years, there have been numerous performance developments in gas generator set technology to improve fuel efficiency, reduce exhaust NO_x emissions and increase ratings. These key development characteristics combined with incentives to develop renewable energy biogas fuel sources have moved the industry forward to consider gas generator sets as the preferred electrical power generation technology for continuous duty applications when paralleled with the utility. In addition, recent expansion of natural gas fuel sources in the United States has resulted in low fuel prices, which is also driving the marketplace to utilize gas generator sets for standby and prime applications typically served by diesel generator sets.

Gas generator set performance improvements have made it difficult to apply modern gas generator sets in standby and prime applications, which require the generator set to react to transient load changes when operating without a utility source.

This white paper aims to provide insight and guidelines to address the performance characteristics found in gas generator sets to help select the correct product for the application.

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RATINGS

Generator set ratings are guidelines to help size the unit to meet the load requirements of the application. There are three common industry generator set ratings for gas generator sets: standby, prime and continuous. Each manufacturer, however, may have different engine tolerances that affect the engine and/or generator set ratings. When choosing a rating for generator sets installed within the United States, the U.S. Environmental Protection Agency (EPA) emission standards for stationary emergency and non-emergency engines must also be considered.

STANDBY-RATED GAS GENERATOR SETS

Suitable for stationary emergency applications where the generator set serves as the secondary power source when the primary utility power source fails. The EPA allows for a maximum of 100 hours of operation annually on either pipeline natural gas or propane fuel sources for maintenance checks and readiness testing.

In these applications, the standby rating is typically specified at a 0.8 power factor. This rating is applicable to variable loads with an average load factor at a percentage of the standby nameplate rating.

PRIME-RATED GAS GENERATOR SETS

Suitable for stationary non-emergency applications where the generator set serves as either the primary or secondary power source when connected to an unreliable utility power source. Prime-rated gas generator sets are typically used for either peak shaving or to provide interruptible power when required by the utility. They can also serve as a secondary power source upon utility failure.

In these applications, the prime rating is typically specified at a 0.8 power factor. This rating is applicable to variable loads with an average load factor at a percentage of the prime nameplate rating for an EPA-allowable unlimited amount of total operation hours.

CONTINUOUS-RATED GAS GENERATOR SETS

Suitable for paralleling with utility applications where the generator set serves as the primary power source. They typically cannot operate as a secondary power source upon utility failure due to their limited transient response capabilities.

In these applications, the continuous rating is typically specified at a 1.0 power factor. The load factor allows the generator set to be operated at full load for an EPA allowable unlimited amount of total operational hours.

PERFORMANCE

Gas engines can be classified as either lean-burn or rich-burn combustion types. Each type has its own advantages and disadvantages depending upon the application. These should be considered when selecting a gas generator system for any project.

LEAN BURN

Applications

Lean-burn engines are associated with high electrical efficiencies. They are typically applied in continuous parallel with the utility applications as a primary power source due to their limited transient response capabilities. Operations without the utility as a secondary power system are usually not possible because typical load steps are below 10% depending on the manufacturer.

Compression ratios

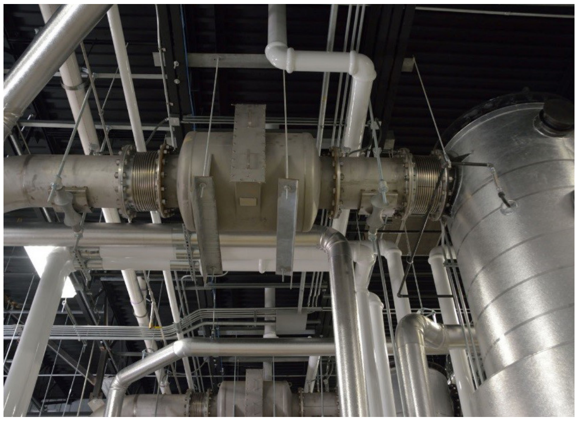
These engines operate at higher efficiencies because they use higher compression ratios typically above 10:1. The electronic Air Fuel Ratio Control (AFRC) system optimizes fuel consumption thus providing generator set electrical efficiencies above 35% for standard combustion systems and above 40% for Miller cycle engines.

To provide improved efficiency and power, modern gas engines require higher compression ratios, making them less tolerant to non-methane based fuel sources. These engines cannot operate on heavy hydrocarbon-based fuel sources such as Liquefied Petroleum Gas (LPG) without a 40% to 60% derate depending on the manufacturer due to the potential for detonation at these higher compression ratios.

Emission requirements

An electronic lean-burn AFRC system is used to provide consistent engine exhaust NOx emission control below 2.0 g/bhp-hr at an oxygen content typically between 8% and 10%. These engines can be operated at NOx emission levels as low as 0.5 g/bhp-hr depending on the manufacturer. Engine efficiency is reduced as the exhaust NOx level is reduced below 1.0 g/bhp-hr by approximately 1% to 2%, depending on the engine manufacturer. So operating at the highest allowable NOx emission level is recommended to maximize the electrical efficiency of the gas generator set system.

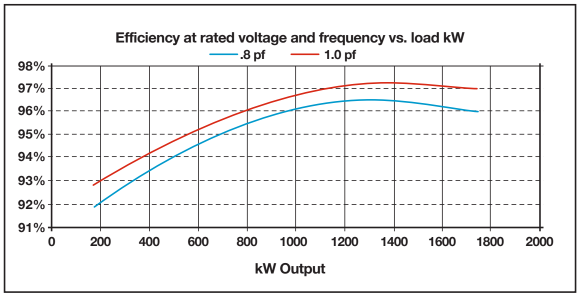
Due to low NOx emission rates, exhaust after-treatment systems are typically not required unless lower CO levels are required to reduce formaldehyde emissions. A Non-Selective Catalyst Reduction (NSCR) system oxidation catalyst is a cost-effective solution to lower exhaust CO emission levels. An expensive Selective Catalyst Reduction (SCR) urea exhaust pretreatment system is required to lower exhaust NOx emission levels if required by the application.



Typical NSCR system

Alternator selection

For continuous-duty applications, a generator set nameplate rating is typically published at a power factor of 1.0, which provides the alternator's best efficiency, thus improving the generator set system's overall electrical efficiency, per this typical alternator chart. The alternator's continuous temperature rise is typically selected at 105°C, which provides the best alternator efficiency with respect to temperature.



Typical alternator efficiency curves

RICH BURN

Applications

Usually associated with applications where transient load response is more critical than fuel efficiency. They are typically applied in emergency standby applications where the generator set system is the secondary power source when utility power is not available.

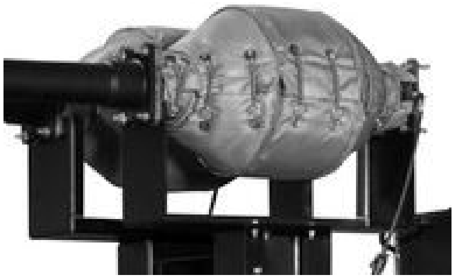
Prime power applications requiring peak shaving or interruptible power applications can utilize these engines if operation without utility power is necessary. These applications typically require 500 hours or less of annual operation, so fuel efficiency is not necessarly a critical factor for selecting these gas generator sets.

Compression ratios

These engines typically utilize an 8:1 compression ratio, which allows the engine to provide the same rating using either pipeline natural gas or LPG fuel sources without derate. Some engine manufacturers utilize a 10:1 compression ratio to improve engine fuel efficiency and power output. Depending on the engine manufacturer, these higher compression ratios, however, will cause a 40% to 60% derate due to the heavy hydrocarbons found in LPG fuel sources.

Emission requirements

Current U.S. emission regulations do not allow rich-burn engine operations without exhaust emission aftertreatment, since their NO_x emission levels typically exceed 15 g/bhp-hr of NO_x. A three-way oxidation catalyst is a cost-effective solution to reduce NO_x emission levels to as low as 0.15 g/bhp-hr. An electronic rich-burn AFRC system is required to maintain the exhaust oxygen content below 0.5%, so the catalyst operates efficiently.



Typical 3-Way catalyst system

Alternator selection

For emergency standby applications, the electrical output is rated at a power factor of 0.8 and a standby alternator temperature rise of 130°C. Alternator selections for prime power applications rate the electrical output at a power factor of 0.8 and a continuous alternator temperature rise of 105° C.

FUEL SOURCES

Gaseous fuel sources can generally be placed in two categories: methane-based fuel sources or heavy hydrocarbon-based fuel sources.

Methane-based fuel sources include pipeline natural gas from petroleum sources which contain up to 95% methane and biogas from naturally decomposing biological materials. Biogas typically contains up to 65% methane. Methane fuel sources can be utilized in high compression ratio, lean-burn engines, as previously defined, without the need for derate.

Heavy hydrocarbon-based fuel sources include LPG from well-head gas and synthetic gas produced from the pyrolysis of biological and solid waste materials. These fuel sources produce high-energy content gases such as propane, butane, hexane, heptane and ethane. They can be utilized in low compression ratio, rich-burn engines, as previously defined, without the need for derate.

Operating on heavy hydrocarbon-based fuel sources in high compression ratio, lean-burn engines, as previously defined, typically require a 40% to 60% derate depending on the manufacturer because of detonation concerns due to the volatile nature of these fuel sources.

An easy way to determine if a gaseous fuel can be utilized in a gas engine is by using the Methane Number (MN) scale with pure methane rated at an MN of 100 and pure hydrogen rated at an MN of 0. This scale serves as a basis for rating fuel mixtures on their ability to resist detonation.

Pipeline natural gas has a typical MN of approximately 90, and LPG has a typical MN of 40. An LPG fuel source is more susceptible to detonation than a pipeline natural gas fuel source. Engine design attributes such as compression ratio, ignition timing, aftercooler temperature and power rating can be changed to limit engine sensitivity to an LPG fuel source.

PERFORMANCE OPTIMIZATION

Most gas generator sets utilize a low-pressure fuel system, which mixes the fuel with the combustion air before the turbocharger compressor inlet. This allows the engine fuel delivery pressure to the engine inlet to be between 0 and 60 inches WC, for most manufacturers. This design can lessen the generator's load step transient response due to the lag in compressing the air/fuel mixture in the turbocharger compressor before delivery to the engine. A pressure regulator installed at the generator set fuel inlet provides the required 0 to 60 inches WC fuel delivery pressure to the engine. This design approach limits the amount of low-pressure piping between the utility fuel source and the engine to minimize pressure loss at the fuel inlet. For low-pressure fuel systems, a nominal fuel source supply pressure between 10 to 30 psi should be provided near the engine to ensure the best achievable gas generator set transient load response possible.

Some gas generator sets utilize a high-pressure fuel system, which mixes the fuel with pressurized intake air after the engine turbocharger compressor outlet. This design typically requires an engine fuel delivery pressure between 50 to 60 psi to overcome the turbocharger outlet compressor pressure. Generator transient response can be improved with this fuel system design, since the air/fuel mixture is blended immediately before delivery into the engine.

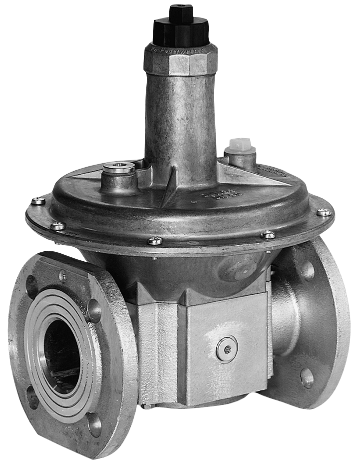
For high-pressure fuel systems, the fuel source supply pressure typically above 50 psi must be provided to the engine fuel inlet. Most utility natural gas fuel sources do not provide high-pressure fuel delivery so a local gas booster must be utilized with oversized utility delivery piping.

As a final test to determine if an adequate fuel supply is provided to the engine, the fuel delivery pressure at the engine fuel inlet should vary less than 1.0 psi when the generator set is loaded to 100%. An analog pressure gauge should be installed at the engine fuel inlet to assist with this test and for future system troubleshooting.

The remaining optimization of the generator set transient response is dependent upon the engine fuel inlet design, which affects how quickly the air/fuel mixture is delivered to the engine. Optimization of the engine electronic AFRC system and fuel mixture valve Proportional Integral Derivative (PID) control loops also play an integral part in optimizing the generator set transient response.

The air fuel equivalence ratio known as Lambda (λ) is defined as the ratio of the actual Air Fuel Ratio (AFR) to the engine at stoichiometry for a given mixture with a $\lambda = 1.0$ being at stoichiometry. Therefore, rich mixtures are $\lambda < 1.0$ and lean mixtures are $\lambda > 1.0$.

The engine air/fuel mixture differences between rich-burn and lean-burn engines play an important role in determining the engine transient load response. The rich-burn engine air/fuel mixture has more fuel energy immediately available to the engine if a large load change is required. Lean-burn engines typically operate at an air/fuel mixture Lambda (λ) level above 1.6, which means more air is present in the mixture to optimize engine efficiency and lessens the amount of NO_x generated in the exhaust. Thus, a large change in the engine fuel control valve will be required to provide the necessary energy to accommodate a large load change. The time required for this fuel to travel to the engine combustion chamber can be excessive, thus causing the engine speed and/or frequency to fall below an acceptable level for the electric power generation system; causing a shutdown due to under frequency.



Typical Pressure Regulator

SUMMARY

In general, rich-burn engines are a better choice in applications where large transient load changes above 30% are required when the utility is not present. Typically, fuel efficiency is not necessarily a concern in standby applications because they have a limited operational capacity of 100 hours or fewer per year. An LPG fuel source can be utilized in these applications without derate if low compression ratio engines, as previously defined, are utilized.

Lean-burn engines are a better choice in applications where the utility is always present, and the required operational capacity exceeds 8,000 hours per year. Fuel efficiency is a key consideration in continuous applications, so engines with high compression ratios are typically utilized. Heavy hydrocarbon fuels such as LPG cannot be utilized in these applications without significant engine derate.

ABOUT THE AUTHOR

Clay Hardenburger is a Senior Staff Applications Engineer with Kohler Co. He holds a bachelor of science degree in agricultural engineering from Kansas State University. Clay joined Kohler in 2015 and uses his 30 years of experience in product design, project engineering and sales engineering to provide custom electrical power generation and cogeneration solutions, focusing on large gas generator set systems.

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