THE IMPACT OF GENERATOR SET UNDERLOADING

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INTRODUCTION

System health and reliability are critical to backup and prime power solutions for every facility, from mission critical data centers to neighborhood grocery stores. A generator set is a key piece of the power system, and proper operation and maintenance are essential to long-term system reliability that ensures availability and uptime.

While power systems vary in operation, application and load profile depending on the purpose and complexity, all power systems are designed with common goals: providing reliable power and maximizing system efficiency. To achieve these design goals, it is important to understand system operation, load profile and schemes, and required maintenance. This paper will focus on the operation of generator sets in low-load scenarios and what can result if they are used outside of these parameters.

GENERATOR SET RATED LOADS

First, it is important to understand that generator sets are designed to run and, to be specific, they are designed to run with load. This may seem trivial, but loading a generator set properly is essential to availability, healthy engine operation and long engine life.

The ideal operation targets of each generator set will depend on the application and rating. Generally speaking, standby- and prime-rated diesel generator sets are designed to operate between 50 and 85 percent of the full nameplate, while continuous-rated diesel generator sets are optimized between 70 and 100 percent load. Natural gas and biogas generator sets, independent of application and rating, are designed for operation between 70 and 100 percent of the nameplate rating.

Manufacturer service intervals and projected component life are based on operation in these ranges to deliver an ideal mix of product performance, power density and long-term operational life. This makes the design phase critical to ensure that the power generation system is sized to operate within the manufacturer's recommended load levels while meeting the facility requirements. Misapplying generator sets by underloading them for extended runs will impact product health, operation and uptime while increasing the opportunity for unplanned events and shutdowns.

DIESEL GENERATOR SETS

Operating a diesel generator set at load levels less than 30 percent of rated output for extended time periods impacts the unit negatively. The most prevalent consequence is engine exhaust slobber, which is also known as exhaust manifold slobber or wet stacking. Engine slobber is a black, oily liquid that can leak from exhaust manifold joints due to extended low- or no-load scenarios. Running at high idle with little or no load reduces the heat in the cylinder, allowing unburned fuel and oil deposits to leak through the exhaust slip joints.

Visible slobber does not necessarily indicate a problem with an engine, but it signals possible underloading concerns, low ambient temperatures or low jacket water temperature. In most circumstances, engine slobber alone, while unsightly, will not immediately harm an engine. However, slobber is a sign of underloading and could be an indication of other underloading effects. Long periods of light loading can lead to deposit build-up behind the piston rings, deposits developing inside the cylinders and, in extreme cases, cylinder liner polishing can occur. These conditions can lead to power losses, poor performance and accelerated wear of components, which can cause increased maintenance costs and unplanned downtime or failure.

GAS GENERATOR SETS

Gas generator sets above 1000 kW are typically used in prime power and non-emergency standby applications where the load profile is steady and at higher load levels. Optimal operating conditions for gas generator sets can range from 50 percent to 100 percent of the rated load. Caterpillar recommends not loading natural gas generator sets in any application below 50 percent of their rated load for any duration, and the ideal range for operation is at 70 percent load and above.

Gas engines do not typically slobber, but there are other effects of low-load operations. At low load, gas engines do not have enough cylinder pressure to maintain oil control in the cylinder. This allows the oil to work its way past the rings into the combustion chambers, leading to ash deposits. These deposits change the compression ratio, which can reduce the detonation margin. If the detonation margin is reduced sufficiently, detonation can occur. Detonation will decrease the life of the engine, damage components and lead to unplanned shutdowns or failures.

Similar to diesel generator sets, the extended operation of gas generator sets at low loads can lead to deposit build-up on the valves, spark plugs and behind the piston rings. In extreme cases deposits in the cylinder can develop, causing cylinder liner polishing.

Additionally, natural gas engines run rich at low loads to maintain combustion and ensure that the engine does not misfire. A rich air-to-fuel ratio causes the engine to deviate from the expected emissions levels, potentially leading to non-compliance with required emissions regulations. Also, a rich air-to-fuel ratio increases temperatures and can accelerate component wear.

As is the case with diesel generator sets, all of these conditions can result in power losses, poor performance and accelerated wear of components, resulting in increased maintenance costs and unplanned downtime or failure.

AFTERTREATMENT

Aftertreatment components such as diesel oxidation catalysts (DOC), selective catalytic reduction (SCR) components and diesel particulate filters (DPF) are commonplace in many locations and applications, and they are all impacted by low-load operation. Without proper design and planning, low-load operation will have an impact on all aftertreatment components, causing emissions targets to be missed and ultimately leading to engine shutdown.

A DOC or DPF that is operating below the minimum exhaust temperature can cause back pressure limits to reach critical levels in a short period of time and lead to generator set shutdown. This issue becomes more critical in distributed or modular systems where there is no paralleling capability to share load between multiple units and ensure that a generator set is not operating at low loads for extended periods of time.

Meeting the minimum temperature is also critical in applications with an SCR system. If the SCR system does not reach the minimum operating temperature, the system will not begin dosing diesel exhaust fluid (DEF) into the exhaust stream, causing higher than expected emissions levels and impacting federal or local site permits.

Some SRC systems may need to be equipped with an additional exhaust heater to help meet minimum exhaust temperature requirements. While this may help maintain temperature needs, it also requires additional load to operate, which increases system complexity, cost and maintenance, and it does not address the impact of underloading on the engine. A more effective approach is to ensure that each generator set meets its minimum load targets for improved long-term system reliability and durability.

LOW LOAD MANAGEMENT

If maintained properly, diesel and gas generator sets can operate at light loads for long periods of time with no harmful effects. After operation at low load levels, each impacted generator set should operate under increased load to raise the cylinder temperature and pressure, which cleans the deposits from the combustion chamber. In addition, if low load operation is expected to occur regularly, a more aggressive maintenance plan will help to ensure that there is no excessive component wear and the chances for unplanned downtime are minimized.

The first major consideration in managing low load is how to add load to a system if the building load is not enough, or if the customer does not want to use critical loads for generator set maintenance. This issue can be resolved by having access to installed system load banks or a quick connect system that will allow for load banks to be easily tied into the power system for testing or maintenance purposes. Accounting for these requirements during the design phase allows for seamless integration into the system, which can be more cost effective than having to retrofit a site after construction and installation are complete.

Caterpillar recommends a testing process for diesel and natural gas generator sets. For diesel generator sets, Caterpillar recommends loading the generator set to a minimum of 30 percent load for approximately 30 minutes for every four hours of light load operation. Exhaust temperature measurements should be taken at the exhaust manifold prior to the turbo or in the exhaust stack just after the turbo to confirm that the recommended exhaust temperatures are met during operation.

The requirements for natural gas generator sets are slightly different. First, Caterpillar recommends aggressively working to limit underloading natural gas generator sets. See Table 1 below for time limits on low load operation for natural gas engines. After the time limit for reduced load operation has expired, the engine should be operated for a minimum of two hours at a load factor of at least 70 percent. Following these guidelines will keep engine maintenance to a minimum and improve long-term product health and durability.

For more information on generator set maintenance and testing, please contact your local Cat dealer or reference the operation and maintenance manual.

Engine Load	Time Limit
0 to 30 percent	1/2 hour
31 to 50 percent	2 hours
51 to 100 percent	Continuous[1]
[1] For continuous operation, the manifold air pressure must be greater than the atmospheric pressure.	

Table 1: Time limits for low load operation of natural gas generator sets.

CONCLUSION

Underloading your power system impacts many individual components as well as overall system performance. While the simple solution is ensuring that your operational load is above 50 percent of the generator set nameplate, actual site conditions, site requirements and site expansion do not always line up with initial system design plans. This makes system underloading prevalent in the power generation market, specifically in the standby market. To help minimize the effects of underloading, it is critical to have operation and maintenance plans in place to maintain the health and reliability of the complete system and your generator set.

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