A Holistic View On Generator Set Ratings

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INTRODUCTION

Many generator set manufacturers mirror their equipment power rating classifications (standby, prime, and continuous) after the ISO 8528-1 standard. The ratings are defined in terms of maximum power available, load factors, hours of usage per year, peak demand, and typical applications. These broad definitions are intended to cover a wide range of industrial and commercial uses. Because of this variability, some manufacturers, e.g. Caterpillar, have chosen to adopt the standard definitions in their most conservative form to minimize the risk of equipment misapplication. Compliance with these standard ratings only indicates the minimal requirements a generator set would meet, under a wide range of applications, but these ratings do not generally specify the full capabilities of the equipment. Some manufacturers have chosen to be more aggressive in their rating definitions to create the appearance of higher capabilities. The aim of this paper is to educate the reader on factors to be considered when selecting a particular rating for a given application.

BACKGROUND

By and large, most engine parts and components are developed to meet or exceed the expected life of the engine (or time to overhaul) when operated at the continuous rating. Overly aggressive use, i.e. operating well above the continuous rating for extended periods of time, could result in accelerated wear and unplanned downtime. At the opposite end, overly conservative use could also affect engine life due to underloading, and it may not provide optimum value to the owner. Hence, a myriad of factors are considered in the development of an engine. Broadly speaking, the design constraints can be lumped into the following categories:

- Structural – Relates to the operating stress levels of components in relation to the endurance limits of the materials
- Thermal – Relates to the impact on material properties due to microstructure changes in the material at elevated temperatures
- Wear – Relates to the impact on material loss associated with cyclical relative motion at high stress levels and elevated temperatures

Within these broad categories, there are many considerations that play a critical role in determining the robustness of an engine. Among the primary considerations driving limits are:

Peak Cylinder Pressure

- Structural impact due to increased vibration and the effect on the main caps, head/block joint, and wrist pins
- Thermal fatigue in components such as the cylinder, block, heads, and pistons
- Increased wear in the valve seats, piston rings and main bearings

In-Cylinder Temperature

- Thermal fatigue due to increased heat on the bottom head deck, piston crater rim, and exhaust ports
- Accelerated wear of the valves and valve seats
- Other considerations, such as overcooling pistons

Exhaust Temperature and Pressure

- Structural impact due to vibration on the manifold head gasket joint, turbo gasket joint, and slip joint
- Thermal fatigue and oxidation of the manifold, valves and guides, turbo and manifold studs
- Wear and erosion of the exhaust manifold

Maximum Injection Pressure

- Mechanical fatigue in the rocker arms/shaft, studs, and injectors
- Heat generation in the injectors

It is clear that high loading conditions and elevated temperatures for extended periods of time would push the previously listed variables toward their upper limits, and have a higher cumulative effect on structural, thermal and wear factors. Balancing all these factors is of paramount importance in developing a robust engine. Caterpillar has a wealth of knowledge on engine design, and applies it to the development of each engine, and to the determination of precise ratings, ensuring that the equipment will meet Caterpillar's stringent reliability and durability goals.

The preceding discussion focused on factors influencing engine rating. The next genset design consideration is the alternator rating. Typically, alternators are thermally limited by the amount of internal heat that is created and the ability to dissipate that heat. As a result, some heat is retained within the alternator raising the temperature of the unit above the ambient temperature. A critical variable is the rise in winding temperature above the ambient temperature. This temperature rise is due to the flow of current in the windings and internal losses that occur in the machine during operation. Hence, operating at higher loads would lead to higher winding temperatures.

The allowable limits on temperature rise are documented in various standards[1-5] for different insulation material classes. Some manufacturers reference lower ambient conditions than those cited by the standard creating the impression of higher temperature rise capability for a lower class insulation, which is of course not the case. Caterpillar follows the standard by specifying temperature rise capabilities based on continuous-duty operation at 40°C ambient conditions (temperature of the cooling air as it enters the ventilating openings of the machine). For alternators with a standby rating NEMA makes an allowance for an additional 25°C over the maximum temperature rise for continuous-duty operation.

Operation at these standby temperature rise values would cause the alternator insulation to age thermally at about four to eight times the rate that occurs at the continuous-duty temperature rise values. However, given that typical usage of standby units is less than 500 hours a year, compared to approximately 8000 hours for continuous duty, operation at standby temperature rise values would not lead to premature insulation aging if the application guidelines for an emergency backup power source are followed, and it is not used as a prime power supply. Therefore, in order to maximize customer value, standby units are generally undersized relative to continuous-duty units.

In certain cases it may be desirable to mate a standby rated engine with a continuous-duty alternator if loading conditions were expected to fall in between those of the general standby and the prime rating. Furthermore, the load type plays a key role on whether an oversized alternator would be required. For example, high harmonic and non-linear loads lead to higher iron core losses, additional heating, and they adversely affect alternator windings (they may cause the winding's end turns to destructively vibrate, leading to insulation cracking, and making the alternator more susceptible to moisture failures). A sound practice is to use oversized alternators to mitigate harmonic loading and minimize voltage distortion (using lower impedance alternators.) Last but not least, careful consideration must be given to the environment and site conditions (altitude, temperature, air flow restrictions, etc.) in which the generator set will be operating. If these conditions are outside the norm they could prevent the generator set from meeting performance expectations. The reader is referred to the Application and Installation Guide published by Caterpillar[6].

In short, Cat® engine and alternator rating guidelines are based on a collection of generator set design limits that are used during rating developments to ensure that the equipment will meet the required reliability and durability goals under a wide range of applications. If the scope of use were to be more narrowly defined, and the range of conditions were more tightly controlled, application-specific ratings could be developed that would enable operation of the equipment closer to its full capabilities with minimal impact on thermal, structural or wear factors and risk of downtime. Caterpillar offers a portfolio of generator set ratings designed to provide coverage from general to special purpose applications while maximizing owner value.

RATINGS DEFINITIONS

Caterpillar uses the ISO 8528-1 standard as the basis for generator set power rating classifications. The standard defines general rating categories and establishes the permissible average power output (load factor) for each one. Caterpillar uses these definitions and provides additional ratings to more closely match rating selection to typical applications. The table provided in the appendix summarizes the Cat ratings and compares them to the ISO ratings. The reader is also referred to Publication LEXE0047 for full coverage of Cat generator set rating definitions[7]. The main five ratings offered for Cat generator sets are:

- Emergency Standby (ESP): Intended for building service standby applications for less than 200 hours per year.
- Standby: Intended for standby service applications for a maximum expected usage of 500 hours per year.
- Mission Critical Standby: Intended for standby service applications for a maximum expected usage of 500 hours per year, at a higher average permissible load factor than the standby rating.
- Prime Power: Intended for high hour operation for remote installations, peak shaving applications, rental, and co-generation with varying loads.
- Continuous: Intended for operating at 100% of the nameplate rating for extended periods of time in base load or operating as the utility source for remote sites.

Given these multiple ratings, it would be natural to assume that there are significant differences in the equipment itself from one rating to the other. By and large, in the modern world of electronically controlled engines, that is not the case at all. Basically, the software flashed into the electronic control system determines if the engine operates as a continuous, prime or standby unit. In some cases, equipment may be marked with dual ratings, e.g. Prime and Standby ratings. This may be puzzling as load factors are, in some ratings, limited to 70%, others to 85%, and even 100% depending on which rating is being applied. The key lies in how the equipment is used. For example, consider a unit with a Standby rating of 2.5 MW, and compare it to a Prime-rated unit of 2.25 MW. The Prim-rated unit has a 10% overload capacity, the standby unit has no overload capacity, so both are capable of delivering a maximum output of 2.5 MW. Now compare the Prime-rated unit to a Load Management Guideline Prime-rated unit. The former may run at 70% load factor for an unlimited number of hours per year. The latter may run at a maximum load factor of 100% if the operating hours are limited to 500 hours per year with varying loads. This limitation on operating hours is the same as in the standby unit, but with a 100% load factor over a base of 2.25 MW (Prime rating) which is equivalent to 90% load factor of the Standby rating of 2.5 MW. Hence, a standby unit would have the capability of operating at about 90% load factor if the time above that load is minimal. The Mission Critical Standby rating takes into account all these factors, defining a rating that is an aggregation of several others, but it is intended for a specific application. In general, the selection of the right rating results from making the proper tradeoffs between run hours, peak load, and average load. Cat dealers are well positioned to assist customers with their genset rating needs.

Table 1: ISO 8528 and Caterpillar Ratings

ISO 8528 Rating		Caterpillar Rating	
Rating	**Definition**	**Rating**	**Definition**
Emergency Standby Power (ESP)	The maximum power available during a variable electrical power sequence, under the stated operating conditions, for which a generating set is capable of delivering in the event of a utility power outage or under test conditions for up to 200 hours of operation per year with maintenance intervals and procedures being carried out as prescribed by the manufactures. The permissible average power output over 24 hours of operation shall not exceed 70% of the ESP rating.	Emergency Standby Power (ESP)	Typical usage of 50 hours per year with a maximum of 200 hours per year with varying loads. Average variable load factor is 70% of the ESP rating. No overload is available. Nor for maintained utility paralleling applications.
No ISO equivalent		Standby Power	Typical usage of 200 hours per year, with a maximum of 500 hours per year with varying loads. Average variable load factor is 70% of Standby rating. No overload is available. Not for maintained utility paralleling applications.
		Mission Critical Standby	Typical usage of 200 hours per year, with a maximum of 500 hours per year with varying loads. Average variable load factor is 85% of Standby rating. Typical peak demand of up to 100% of the rating for 5% of the operating time. No overload is available. Not for maintained utility paralleling applications.
Limited Time Running Power (LTP)	The maximum power available under the agreed operating conditions, for which the generating set is capable of delivering for up to 500 hours of operation per year with the maintenance intervals and procedures being carried out as prescribed by the manufacturers.	Load Management Guidelines (Prime Power Rating)	Load management is the deliberate control of loads on a generator set and/or utility to have the lowest possible electrical costs. Maximum of 500 hours per year with varying loads. Maximum load factor is 100%. Typical application is peak shaving.
Prime Running Power (PRP)	The maximum power which a generating set is capable of delivering continuously whilst supplying a variable electrical load when operated for an unlimited number of hours per year under the agreed operating conditions with the maintenance intervals and procedures being carried out as prescribed by the manufacturer. The permissible average power output over 24 hours of operation shall not exceed 70% of the PRP rating.	Prime Power	Unlimited hours of usage. Average variable load factor is 70% of the Prime Power rating. 10% overload available, but limited to 1 in 12 hours and not to exceed 25 hours per year. The 10% overload is available in accordance with ISO 3046-1. Life to overhaul of the engine is dependant on operating as outlined in ISO 8528, and time spent during operation above 70% load may affect the life to overhaul.
Continuous Operating Power (COP)	The maximum power which the generation set is capable of delivering continuously whilst supplying a constant electrical load when operated for an unlimited number of hours per year under the agreed operating conditions with the maintenance intervals and procedures being carried out as prescribed by the manufacturer.	Continuous Power	Unlimited hours of usage. Non-varying load factor is 70%-100% of the published Continuous Power rating. Typical pear demand is 100% of the continuous rating for 100% of the operating hours.

Table 1: ISO 8528 and Caterpillar Ratings

RATINGS SELECTION

Cat generator sets are built using robust engines that incorporate advanced engineering, design, and manufacturing techniques to create a product that performs in the world's most rugged conditions. Generator set ratings can be optimized for specific applications if a deep understanding of the loads, load schemes, and how the unit will be applied is taken into account. Then the appropriate operation and load factors can be determined to maximize permissible kW output, durability, uptime, fuel economy, and increased life of the unit. Caterpillar offers an extensive engineering, application, and design knowledge base throughout the Cat dealer network to assist the customer in making an optimum equipment selection. The reader is strongly encouraged to take advantage of this valuable service. What follows is a broad discussion on rating selections and some common misconceptions.

The general rating categories are intended to cover a wide range of industrial and commercial applications. Oftentimes specific applications fall outside the norm. Some present a unique set of challenges; in some cases the selection of a Standby rating may be viewed as overly aggressive, and in other instances the selection of a Prime rating may prove to be overly conservative. For example, ISO 8528-1 standard is very specific on how to calculate load factor on an emergency standby (ESP) unit by defining it as "the permissible average power output over 24 hours of operation shall not exceed 70% of the ESP …" Would the engine stop if the 70% load factor is exceeded over 24 hours? Of course not! Caterpillar takes a more holistic view of the rating definitions. Instead of literally considering a single event or condition as the driving factor for the selection of a standby unit over a Prime-rated one, the overall usage of the equipment is considered over a more application-relevant time frame. For example, the Cat standby rating definition makes an allowance for a unit to deliver 100% of the standby rating for the duration of an outage related to emergency/disaster type conditions under extraordinary circumstances. Such operation outside the limits of the defined rating could have an impact on wear and/or unscheduled maintenance, depending on severity. But these limits need to be put in the context of overall use, in the given application, and over the expected life of the equipment.

Mission Critical applications, e.g. data centers and health care facilities, are special cases where reliable standby power is of paramount importance. In a data center, loss of electrical power could be a financial catastrophe; in a hospital, it could be a human tragedy. By and large, mission critical facilities are located in urban areas where utility availability is high (data centers in particular). Hence, hours of operation for standby generator sets are relatively low. In some cases, the bulk of the use is associated with the periodic exercise of equipment to ensure readiness in the event of an emergency. For these reasons, the Mission Critical rating relaxes the Standby rating requirement on load factor from 70% to 85% given the intended use. Considering the potentially higher average load, and compounding it with the ability of delivering 100% of the Standby rating for the duration of an outage under extraordinary circumstances, Caterpillar recommends using continuous-duty rated alternators for Mission Critical installations. This practice is in full alignment with data center applications where low impedance (oversized) alternators are typically specified. Heath care facilities would also benefit from this choice as it improves the quality of power available to sensitive equipment such as medical imaging devices.

As a final note, additional allowances are sometimes made for certain data center applications for initial commissioning tests where new generator sets are required to run at very high output levels for prolonged periods of time that extend well beyond those outlined in the Mission Critical rating definition. When such exceptional operating conditions are encountered, it is imperative they be reviewed with the factory/dealer to ensure that proper maintenance is conducted so that the long-term health of the equipment is not jeopardized. This is true for any other application as well. The Cat Extended Service Coverage (ESC) coupled with a Customer Support Agreement (CSA) is the best way to ensure that any Cat equipment will operate at peak performance levels all throughout its entire useful life.

SUMMARY

Caterpillar has a wealth of experience in electric power generation offering superior products that are unsurpassed in quality, performance, reliability, and durability. Regardless of the application, Caterpillar manufactures generator sets providing a family of ratings to ensure that the customers' power needs are met and that the generating equipment is protected from premature wear. Choosing the right rating means making the proper trade-offs between run hours, peak load, and average load. The proper rating also means that the customer receives the optimum combination of installed cost and long-term cost of ownership. Cat dealers understand generator set ratings and are well positioned to act as trusted advisors to their customers. They are able to assist with rating choices and act as one safe source for supporting the entire power system. The reader is strongly encouraged to use this valuable resource to select the best generator set for the application.

REFERENCES

1. IEEE Std 115, Guide for Test Procedures for Synchronous Machines
2. ISO Std 8528-1 (2005), Reciprocating Internal Combustion Engine Drive Alternating Current, Generating Sets
3. NEMA Std MG1, Motors and Generators
4. UL 2200, Stationary Engine Generator Assemblies
5. IEC 60034, International Standard for Electrical Rotating Machines, 11th edition, 2004
6. Cat Application and Installation Guide for Electric Power Applications, Engine and Generator Sizing
7. Publication LEXE0047, Understanding Generator Set Ratings

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