Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 013 - Alternator Ratings and Overload

ALTERNATOR RATINGS

AC synchronous generator (alternator) ratings are specified in accordance with national and international Standards (IEC 60034-22: AC generators for reciprocating internal combustion (RIC) engine driven generating sets). There are two types of rating that are specified, Basic Continuous Rating (BR) and Peak Continuous Rating (PR).

Basic Continuous Rating (BR)

Also referred to as Maximum Continuous Rating, Continuous Running Duty - Duty type S1 (IEC 60034-1) or Continuous Duty (NEMA MG1-32). The alternator will have a maximum continuous rating at which the machine may be operated for an unlimited number of hours per year, while complying with the requirements of the appropriate standards.

For industrial use alternators, three Base Continuous Rating levels are offered, based on temperature rise limits and a standards ambient temperature of 40°C:

- Class “H” (125°C/40°C)
- Class “F” (105°C/40°C)
- Class “B” (80°C/40°C)

Peak Continuous Rating (PR)

This discrete constant loads rating equates to a Duty with discrete constant loads - Duty type S10 in IEC 60034-1 or Standby Rating in NEMA MG1-32. Commonly known as the Peak Standby Rating, this rating level allows the permissible alternator temperature rise to increase by a specified amount according to its insulation system thermal classification. For an insulation system with thermal classification ‘H’, the total temperature may be increased by 25ºC for alternator ratings of < 5MVA. The result is an increased rating at the expense of reducing the lifetime of the alternator by between 2 to 6 times of the base continuous rating.

For industrial use alternators, two Peak Standby Rating levels are offered, based on temperature rise limits and ambient temperatures that provide a total temperature 10°C above the total temperature limit for the insulation system. For low voltage alternators:

- Class “H” (150°C/40°C)
- Class “H” (163°C/27°C)

Declaration of Duty – Duty Types.

To determine the correct size of alternator for a particular application, it is important to know the characteristics of the loads to be applied, along with the sequence and duration of each load. IEC 60034-1 effectively guides a declaration of duty and offers Duty Types S1 to S10, to describe the cyclic duration of the loads to be applied:

Continuous running duty – Duty type S1
Short-time duty – Duty type S2
Intermittent periodic duty – Duty type S3
Intermittent periodic duty with starting – Duty type S4
Intermittent periodic duty with electric braking – Duty type S5
Continuous operation periodic duty – Duty type S6
Continuous operation periodic duty with electric braking – Duty type S7
Continuous operation periodic duty with related load/speed changes – Duty type S8
Duty with non-periodic load and speed variations – Duty type S9
Duty with discrete constant loads – Duty type S10

To simplify alternator selection for the many and various load applications, Alternator manufacturers including Cummins Generator Technologies use two Duty Types, S1 and S10:

Duty Type S1 – Continuous running duty – Base Continuous Ratings are used for this type of duty:

Definition: Operation at a constant load maintained for sufficient time to allow the machine to reach thermal equilibrium.

Duty Type S10 – Duty with discrete constant loads – this type of duty is defined for Standby application:

Definition: A duty consisting of a specific number of discrete values of load (or equivalent loading) and if applicable, speed, each load/speed combination being maintained for sufficient time to allow the machine to reach thermal equilibrium.

Clarification of Relative Thermal Life Expectancy or TL Factor.

Factor T_L for the relative thermal life expectancy of the insulation system is an important integral part of the rating class. The exact value for the factor TL is marked on the rating plate.

ISO 8528-1 refers to Emergency Standby Power (ESP) and Limited Time Prime (LTP) ratings and accepts a reduction in life for the Generating Set.

‘The limited time running power is the maximum power which a generating set is capable of delivering for up to 500h per year of which a maximum of 300h is continuous……..it is accepted that the operation at this rating will affect the life of the generating set’

Peak Continuous Rating (PR) – also referred to as Stand-By – when offered by CGT, takes into account the fact that this introduces a reduction in service life and so does need to be qualified with a TL factor.

Based upon the above described duty cycle, a TL factor of 0.844 is advised as being appropriate for the CGT range of alternators when they're offered for a PR rating. This T_L factor advises that the life expectancy of the ac generator will be reduced to 84.4% of the life expectancy of that same ac generator being operated at the published BR Class 'H' rating.

Example:
Consider an alternator with a BR Class 'H' rating of 200kVA. This same alternator has a published PR rating of 212kVA. If operated at the PR rating for 500h per year, the theoretical life expectancy of the alternator will be reduced to 84.4% when compared with operation at the BR rating and a life expectancy of 100% is theoretically expected.

Thermal Classification of the Insulation System and the Limit of Temperature Rise.

Low Voltage (LV) alternators.

The insulation system used on STAMFORD and AvK Low Voltage (LV) alternators has a thermal classification 'H' (180ºC). The 'half life expectancy' of a Class 'H' insulation system operated continuously at a temperature of 180ºC is some 20,000 hours. Although this does not mean that the insulation system will fail after 20,000 hours.

For a Class 'H' insulation system, the limit of temperature rise by the resistance method for a machine indirectly cooled by air, is 125K for the alternator's armature (Stator) and dc field (Rotor) windings. For Classes 'F' and 'B', the limit of temperature rise is 105K and 80K respectively for the above windings.

The LV alternator can be operated at lower temperature rise limits for the alternative thermal classifications 'F' or 'B', with increased 'half life expectancy' of 120,000 hours and 640,000 hours respectively.

Medium Voltage (MV) and High Voltage (HV) alternators.

The insulation system used on STAMFORD and AvK Medium Voltage (MV) and High Voltage (HV) alternators has a thermal classification 'F' (155ºC). The 'half life expectancy' of a Class 'F' insulation system operated continuously at a temperature of 155ºC is some 20,000 hours. Although this does not mean that the insulation system will fail after 20,000 hours.

For a Class 'F' insulation system, the limit of temperature rise by the resistance method for a machine indirectly cooled by air, is 105K for the alternator's armature (Stator) and dc field (Rotor) windings. For Class 'B', the limit of temperature rise is 80K for the above windings.

The MV/HV alternator can be operated at the lower temperature rise limit for the alternative thermal classifications 'B', with increased 'half life expectancy' of 120,000 hours.

Operating conditions.

AC synchronous generators are designed to operate within the following operating site conditions in accordance with IEC 60034-1.

Altitude: The height above sea level does not exceed 1000m.

Ambient temperature: The temperature of the air at the operating site does not exceed 40ºC for industrial applications. The minimum temperature at the operating site is no lower than -15ºC. Should an ambient temperature lower than -15ºC be expected, the customer shall specify the minimum ambient temperature and whether it applies only during transport and storage or also, after installation and so, a part of operational conditions.

Adjustments to limits of temperature rise and of total temperature to take account of operating conditions.

If the specified or resulting maximum ambient temperature is between 40ºC and 60ºC, the limits of temperature rise shall be reduced by the amount by which the ambient temperature exceeds 40ºC. This is achieved by reducing the Base Continuous Rating. Refer to AGN012 Environmental Rating Factors.

If the specified or resulting maximum ambient temperature exceeds 60ºC or is less than 0ºC then the requirements must be referred by email to applications@cummins.com.

If the specified or resulting maximum ambient temperature is between 0ºC and 40ºC, an increase in the Base Continuous Rating may be made with the customer's prior agreement at time of order. The increase in the temperature rise shall not exceed the amount by which the ambient temperature is less than 40ºC, with a maximum of 30 K. Refer to AGN012 Environmental Rating Factors.

Altitude rating adjustment to take account of operating conditions.

If the machine is to operate at an altitude exceeding 1000 meters above sea level, refer to AGN012 Environmental Rating Factors.

Underwriters Laboratories (UL) Compliance.

The insulation system used on alternators manufactured by Cummins Generator Technologies is a class 'H' system for LV and a Class F system for MV and HV, as specified and described by **U**NDERWRITERS **L**ABORATORIES of the USA.

U.L. have established operating temperatures and associated life expectancy levels for all the electrical insulation materials available and group these materials into the various classes familiar to all those involved with electrical equipment.

When considering the aspects that govern the expected life of an alternator, the thermal rating is important, but so many other factors need to be taken into account. These include any atmospheric contamination that could affect the insulation life and vibration levels that can damage bearings. Also, component assemblies and the characteristics of the electrical equipment being supplied. If the application of this equipment has large, or repetitive, impact loads, such as motor starting or transformer energising, or consists of non-linear loads and therefore high harmonic levels are present, the overall life expectancy of the alternator will be affected.

Duty Cycle: ISO 8528.

Internationally recognised terminology for Generating Set duty cycle definitions are related thermal ratings are included in ISO 8528. There follows; extracts taken from the ISO 8528 engineering standards, for engine driven power generation equipment packages.

ISO 8528 consists of the following parts under the general title: Reciporcating Internal Combustion Engine driven Alternating Current Generator Sets:

- Part 1 : Application, ratings and performance
- Part 2 : Engine
- Part 3 : Alternating Current generators for generating sets
- Part 4 : Control gear and Switchgear
- Part 5 : Generating Sets
- Part 6 : Test Methods
- Part 7 : Technical declarations for specification and design
- Part 8 : Requirements and tests for low-power generating sets
- Part 9 : Measurement and evaluation of mechanical vibrations
- Part 10 : Measurement of airborne noise by the enveloping surface method
- Part 11 : Rotary uninteruptible power systems – Performance requirements and test methods
- Part 12 : Emergency power supply to safety services

The following table summaries the rating definitions in ISO8528-3 and IEC 60034-1 for the Alternator and ISO 8528-1 for the Generating Set:

Genset Rating (ISO8528-1)	**Emergency Standby Power** (ESP)	**Limited Time Prime** (LTP)	**Prime Rated Power** (PRP)	**Continuous Operating Power** (COP)
Load type	Variable	Constant	Variable	Constant
Annual operating hours	200	500	Unlimited	Unlimited
Average load	70%	100%	70%	100%
Overload	No	No	10% (1 hour in every 12 Hrs)	No
Alternator Rating (NEMA MG1-32)	Standby	Standby	Continuous	Continuous
Duty Cycle (IEC 60034-1)	S10	S10	S1	S1
Alternator Ratings	Standby 150/40 Standby 163/27	Standby 150/40 Standby 163/27	Class H 125/40 Class F 105/40 Class B 80/40	Class H 125/40 Class F 105/40 Class B 80/40

OVERLOAD

If an alternator is operated above its designed Base Continuous Rating, the operating temperatures will increase to a level that will degrade and so, shorten the life of, the wound components of the insulation system.

For a fixed percentage overload, the rate at which the operating temperatures increase is a product of the alternator's Thermal Time Constant. This thermal time constant factor varies in proportion to:

1. The physical mass of the wound components, which in turn affects the rate of thermal rise. For example; larger alternators up to 300kVA cope better than small alternators with outputs around 50kVA.

2. The percentage level of overload above the alternator's designed Class 'H' rating.

3. The duration of the overload condition.

4. The operating temperature of the wound components just before the overload condition begins.

5. The ambient temperature during the overload condition.

An alternator's ability to cope with an overload condition is described by the Thermal Life [TL] factor ascribed to each alternator design.

Alternators manufactured by Cummins Generator Technologies are designed to comply with all appropriate National and International Standards concerned with the performance and capability of rotating electrical machines. Some of these Standards have been in existence for many years and may no longer represent current power engineering practice, generating industry trends, or Generating Set customer's expectations for Generating Sets that incorporate modern technology diesel engines and alternators.

An example of an 'Old' Standard is BS 5000pt3, and the section that refers to "10% overload for One hour in twelve". This requirement is often quoted, but the following part of the same section is often forgotten or ignored. The Standard qualifies this 10% Overload for 1 hour in 12, as a condition that will result in winding over-temperature condition that will shorten the life of the insulation system and a condition that is only allowable in an ambient temperature not exceeding 27C.

Because of misunderstandings arising around the many and varied national standards, including the "10% overload for 1hour in 12" with no clarification of the conditions, a new global, International Standard specific for Generating Sets has been written under the guidance of ISO and numbered ISO 8528.

Refer to the ISO 8528 comment later in this guidance note.

Occasional excess current and maximum momentary overloads.

IEC 60034-1 states that an alternator must be capable of withstanding occasional excess current equal to 1.5 times the rated current for not less than 30 seconds, for rated outputs not exceeding 1200MVA.

The maximum momentary overload specified in NEMA MG1-32 is that a synchronous ac generator with a synchronous speed less than or equal to 1800rpm, shall be capable of carrying a 1 minute overload at 150% of normal rated current. For synchronous speeds over 1801rpm, the synchronous ac generator shall be capable of carrying a 1 minute overload at 130% of normal rated current.

The excess current capability and maximum momentary overloads are given for the purpose of co-ordinating the alternator with control and protective devices.

110% Overload for one hour in twelve consecutive hours running.

In addition, alternators having a Base Continuous Rating as defined above, shall be capable of delivering 110% rated output at rated voltage and rated speed for one hour during any period of twelve consecutive hours running, provided that the inlet coolant temperature during the overload period is below that corresponding to the maximum inlet coolant temperature for which the machine has been rated, by not less than 13K. No temperature rise limits are specified for this overload condition.

The reference temperature for the ISO 3046-1 diesel engine overload is 27ºC, and with this inlet coolant temperature an alternator rated for Base Continuous Rating is permitted an additional 13K. Even with the 13K reduction in ambient temperature specified, any significant usage of this 10% overload capacity will shorten the insulation life expectancy of the machine.

110% Overload for 2 hours out of any 24 consecutive hours of operation.

NEMA MG1-32 states that diesel engine specifications often call for machines that are suitable for 10% overload for 2 hours out of any 24 consecutive hours of operation. Generators having a corresponding overload capability are sometimes required. In such cases, it is recommended that the alternators and their excitation systems be designed to deliver 110% of rated kVA at rated power factor, frequency, and voltage with temperature rises under rated load conditions not exceeding the limits of temperature rise.

Short Circuit Conditions.

Digital and MX type AVR's have an over-excitation detection circuit which will, after a pre-set non-adjustable time delay, stop the AVR giving an output to the exciter field, should the alternator be subjected to any condition of overload and therefore, over-excitation, which activates this over-excitation [voltage] detection circuit.

This detection circuit is a basic voltage monitoring circuit which, when activated starts an 8 second delay timer. If, after the 8 seconds, the over-excitation condition still exists, the AVR will stop exciting the alternator as a self-protection scheme.

Now, this 8 second time period can be allowed to run its full time if the overload is a balanced, three phase condition, where the resulting fault current is typically, some three times rated current.

For unbalanced fault conditions, where the resulting fault current levels will be considerably higher than three times rated current, it is most important that suitable Circuit Breakers have been fitted to the electrical protection system to clear the fault in the following times:

Fault Condition – Typical Fault Current Maximum Time.

- 2 phase Line to Line Fault 5 times rated *In* 5.0 seconds
- 1 phase Line to Neutral [earth] 8 times rated *In* 2.0 seconds

The AVR's over-excitation protection system must not be used to protect against 2-phase and 1-phase fault conditions.

In fact, the AVR's over-excitation system should only be considered to be a **secondary** back-up protection scheme; the **primary** protection system being correctly rated and set Circuit Breakers.

Fault Conditions with Series 4 (AS AVRs and SX AVRs) Control Systems.

Alternators fitted with AS or SX type AVR's have no sustained short circuit current capability. The alternator's sub-transient reactance (X''d) and transient reactance (X'd), along with time constants, produce the initial fault current levels, which, after some 0.25 seconds have fallen to zero.

However, there will be a low level of current flowing around the fault [short] circuit and this current level will be in the order of some 5% of the rated current. This fault current flows because of the residual magnetism retained within the exciter field lamination steel. It is this residual magnetism that produces the residual voltage, which enables the alternator to self-excite every time the alternator is started. Typical residual voltage levels are in the order of 15% to 20% of rated output voltage.

ISO 8528 – COMMENT

The '*old way'* of specifying an overload capability which, within the Genset industry is often called a "Standby rating", was to increase the Generating Set's normal Continuous Base Rating by a straight 10%, but specify this rating for a ONE hour period in every 12 HOURS. The time period often being reduced by the "keen" Generating Set builder and sometimes offered as "10% for One hour in Six".

This *'old way'* of doing things was fine, until all manufacturers of alternators started to run our machines at real maximum Class 'H' temperature rises, when the Engine manufacturers were running their equipment at very high BMEP figures too.

This brought about the introduction of an International standard ISO 8528, which recognised the need for a re-think about identifying and quantifying, the Ratings and Duty Cycle for equipment that was to be operated above the normal continuous industrial ratings. Conditions where the operating temperatures for the alternator's insulation system and the engine's load/wear rate would be such that it would suffer from quantifiable thermal degradation.

Typically, this can be a factor of TWO to SIX times the reduction in Life Expectancy. So the **'half-life'** for the insulation would reduce from the normal 20,000 hours to as little as 3,300 Hours, which is only a continuous period of 20 weeks. Then consider the additional risk of degradation due to Chemical and Mechanical Vibration, to the thermal degradation and the risk of insulation failure becomes so likely that the careful validation for such applications is always required.

It is for this reason that ISO 8528 covers the whole situation of what qualifies and quantifies an overload situation and what qualifies and quantifies a Standby Duty. The basic description of Standby is: Standby to support the connected load for the duration of a Mains Supply failure and this should be for a continuous running period, not exceeding the Engine manufacturers maintenance specifications and in most cases, this means up to 300 hours per year, although ISO8528 is not specific, and this value varies with different designs from the manufacturers of engines and generators. This situation should not occur for more than TWICE in any 12-month period and it is accepted by the end user that the life of the Generating Set will be reduced by such operating conditions.

As the heating effect of the load kVA on an alternator follows a square law, operating above the normal Class 'H' Base Continuous Rating becomes a study of the ability of the alternator's active components [iron & copper] to heat soak short term overload conditions and not reach thermal instability under the longer running time period 'Standby' conditions.

Studying the square law graphs from alternator heat runs to identify the possible standby ratings means that the subtleties about each individual design condition of Flux level and Current density means that there is not a true one-off multiplying factor that holds good across the entire CGT Range.

The Ratings Books have the approved Standby Ratings for ambient temperatures at both 40°C and 27°C. If you were to study these ratings, then you would form an opinion that a typical multiplier would give an extra 4% at Standby 40°C and an extra 7% at Standby 27°C.

If a particular Generating Set has ratings above the Ratings Books' values, then what are the justifying conditions; might they be the local ambient temperatures, or a locally agreed Duty Cycle, or the alternator has a special winding design for fixed voltage operation, or are these ratings for a Generating Set build that has small Engine / big alternator and therefore, relate to the Engines overload capability, where the alternator is never being forced above its Ratings Book values.

In summary: ISO 8528 makes no reference to '10% overload for 1hour in 12'. Instead, it refers to electrical outputs for two specific fundamental applications and because of difficulty in ensuring that an agreed overload time limit is not exceeded, it considers load conditions which could exist long enough for the alternator and engine to reach thermal equilibrium under the specified load condition and site environment.

Engine manufacturers offer their products with various output ratings including PR ratings and therefore, Generating Set manufacturers are able to choose cost effective engines and alternators in order to be able to offer Stand-By [PR] rated equipment.

SPECIAL RATINGS FOR UC224 AND UC274 WINDING 311 ALTERNATORS

Background.

Back in 2002, the introduction of Finite Element Analysis tools to consider improvement of existing design capabilities, identified a potential stress level associated with the magnetic saturation of the Winding 311 design when operating at 440V, 50Hz.

The response was to conduct machine testing and this confirmed that high excitation levels occurred and therefore, the winding assemblies (particularly the Rotor winding) were operating above acceptable levels for the longevity of Class H insulation materials.

Due consideration at that time identified very few applications requiring 440V, 50Hz and therefore the business took the decision to remove 440V ratings from all external publications.

Customer response.

It should be noted that up to the point of withdrawal of these ratings and initially beyond, no warranty issues, or reports of burn-outs have been specifically attributed to 440V, 50Hz operation.

Safe ratings.

Obviously, there must be safe ratings that can be applied to the UC224 and UC274 alternators globally produced products for operation at 440V, 50Hz. It is important to take into account, at this point, the variations in performance of electrical lamination steels we use globally.

The following table shows “safe” ratings (based on available test data) that can be applied:

Frame and Core	Class H rating at 415V, 50Hz (kVA)	Class H rating at **440V**, 50Hz (kVA)	Class F rating at 415V, 50Hz (kVA)	Class F rating at **440V**, 50Hz (kVA)
UCI224C	42.5	**30**	37.5	**27**
UCI224D	50	**38**	45	**34**
UCI224E	60	**45**	53	**40**
UCI224F	72.5	**55**	65	**49**
UCI224G	85	**75**	75	**67**
UCI274C	100	**85**	84	**77**
UCI274D	114	**97**	100	**87**
UCI274E	140	**119**	125	**107**
UCI274F	160	**136**	145	**122**
UCI274G	182	**153**	164.6	**138**
UCI274H	200	**170**	182	**153**
UCDI274J	230	**196**	210	**176**
UCDI274K	250	**213**	229	**191**