Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 041 – Alternator Operating Speed

INTRODUCTION

AvK and STAMFORD synchronous a.c. generators (alternators) are designed to meet the requirements identified in IEC60034-1 and NEMA MG1 Part 32. These alternators are designed to operate at a driven speed to provide an electrical output at the ideal international voltage and frequency appropriate for the connected electrical equipment. Furthermore; the Generating Set manufacturer is expected to incorporate the alternator in to a Generating Set that has been designed to comply with the expectations of the connected load and will therefore, have a prime mover with a governing system that will 'hold' the speed, therefore output frequency, within specified limits.

There are various speed governing classes against which prime movers can be specified and these can be found in ISO 3046-4 and BS 5514 Part 4. Any application that requires the alternator to operate over a speed range greater than an M1 Performance Class should be discussed with the Application Engineering. Contact applications@cummins.com.

AvK and STAMFORD alternators are designed to be operated with a speed governing system that will operate at 5% above the nominal synchronous speed at 'No Load', with the speed dropping to the nominal synchronous speed at full rated output. Under such speed control the alternator performance will comply with all published data.

LOW SPEED OPERATION

AvK and STAMFORD alternators are designed to supply at a fixed frequency of 50Hz or 60Hz, based on the required electrical output. The alternator will operate at the published continuous rated output if the speed is allowed to drop by up to 1Hz below the nominal synchronous speed.

If the speed falls to some 2.5Hz below nominal, then the alternator's Automatic Voltage Regulator (AVR) protection circuit will be activated by the automatic UFRO – Under Frequency Roll Off – circuit.

The typical expectation for low speed conditions is that they are temporary short term conditions that have occurred due to a sudden increase in load and have resulted from the engines inability to transiently maintain nominal speed. Under such conditions, the UFRO facility becomes active and reduces the alternator output voltage, safeguarding the wound excitation components. Additionally, it effectively reduces the applied electrical load, aiding engine recovery.

Slow running speed reduces the performance of the cooling fan and prolonged slow running speed promotes alternator components to conditions of overheating. Slow running speed also causes the alternator to operate at higher magnetic flux levels in attempt to maintain the set output voltage. This situation overheats / overloads all the excitation components and also the stator lamination steel.

All AVR's have a speed / voltage threshold known as the 'build-up' threshold. Above this threshold the power supplies for the electronics are at the designed level and the AVR functions as intended. Below this threshold, the AVR power supplies reduce in voltage until the electronic circuits cease to function, resulting in little or no output from the AVR.

If a situation arises where the Generating Set speed is exactly or fluctuating around the build-up threshold, then the alternator voltage can be at an undetermined value between zero and a value approximately proportional to the product of rated voltage and speed (per unit). This can cause relays and sensors in the Generating Set control system to signal confusing information about the exact state of the alternator and is therefore best avoided.

If an engineered situation is likely to occur that involves running at reduced speeds for a sustained period, it is preferable to isolate the alternator's excitation system.

It is recommended that, if the running speed is to be reduced to below 37Hz, for more than ONE minute, then the alternator excitation circuit should be isolated. For STAMFORD alternators fitted with an Analogue AVR, this is accomplished by open circuiting AVR terminals K1 - K2. For AVR's that do not have K1 - K2 terminals, consult the Application Engineering. For AvK products, contact Application Engineering. Contact applications@cummins.com.

OPERATING AT VARIABLE SPEEDS

By the very nature of their design, we need to apply some basic considerations to enable an ac synchronous generator (alternator) to operate over a speed range, where the maximum operating speed for a typical 4-pole alternator is 2000rpm and the minimum operational speed is 750rpm (over-speed maximum is 2250rpm for 2 minutes).

When operating a conventional (IC01) air cooled alternator over a speed range, then reference must be made to the following factors to ensure the alternator's excitation levels and so

resulting magnetic flux levels, along with the wound components operating thermal conditions are all kept within design limits.

As a point of reference, consider a STAMFORD 4-pole alternator with standard Winding 311 or 312. It is accepted that this winding design has a speed range and at each speed the alternator will be operating at the 'ideal' 100% magnetic flux level.

Speed RPM	Hz	Output Voltage
1500	50	400
1800	60	480

Operational speed envelope

Output Voltage Calculation Factor

When reducing the running speed, the alternator output voltage must be reduced proportional to speed in order to prevent any damage by over fluxing the alternator.

For example; at 45Hz the output voltage corresponding to an ideal flux level is based on the calculation on a known acceptable reference point:

Voltage output at 45Hz = 480V x (45/60) = 360V

Output Rating Calculation Factor

To determine the rated output available under a reduced speed and so reduced cooling airflow capability, can be identified by the following formula:

(Operating frequency / Nominal frequency) $^{1.5}$ x Name plate kVA at nominal Hz

For example; an alternator rated at 500kVA, 480V, 60Hz is to be operate at 360V 45Hz and so what will the output kVA rating now be:

500kVA x $[(45/60)^{1.5}]$ = 325kVA which at 360V, is 521A.

Note. The above formula considers thermal heat transfer characteristics resulting from reduced air flow quantity and velocity. This rather basic ^1.5 rule should only suitably be used when considering speeds down to 750rpm (25Hz).

Generating Sets for a Variable Speed Range

The object of the following information is to assist with considerations for a suitable Generating Set to operate over a wide speed range. A typical application would be a Generating Set operating in conjunction with a Wind Turbine:

1. To keep the excitation levels within acceptable design limits, the alternator's output voltage must change by a ratio proportional with the operating speed.

2. Reduced operating speed results in reduced fan speed and so less effective cooling being provided for the alternator's wound components.
3. The combined effect of 1 and 2 above result in the alternator's output kVA rating being modified by a square law for speeds below 1500 rev/m: 50Hz. For speeds above 50Hz, the increase in rated output follows the Generating Set industry norm of speed ratio to the power of 1.25. This is explained in detail below, in this AGN.
4. The alternator's excitation system must be capable of 'building up' into a connected load at the expected relatively low operating speeds, where 750 rev/min. should be considered the minimum acceptable speed to begin to load the Generating Set. Refer to the Section on low speed operation above, in this AGN.
5. It is likely that the Generating Set would be connected to an electrical system that rectifies the generator output and so introduces harmonic distortion onto the electrical output. Most small variable speed wind turbine Generating Sets are connected to an electrical system that rectifies the Generating Set output, and so introduces harmonic distortion onto the electrical output.
6. With many variable speed applications, we must also consider reliability issues created by environmental conditions, which may introduce component damaging vibration levels associated with the wide speed range, drive mechanism and torque pulsations. Operation in conjunction with a wind turbine, for instance, will introduce reliability issues created by environmental atmospheric conditions, and may introduce component damaging vibration levels associated with the wide speed range, drive mechanism and torque pulsations.

From this you will see that each variable speed application must be considered on its individual characteristics. This means as much detail as possible must be considered on the operating parameters and environmental conditions, to enable the correct type and size of alternator to be determined for that particular application. Simply put; there is no one-size-fits-all for these variable speed applications.

For example; the design of the alternator is such that the output voltage must remain proportional to speed over the range 750< 2000 rev/min. This is the data for the S4L1S-F Winding 311 alternator, rated at 400kVA, 400V, 50Hz:

Speed / Hz	Voltage L-L	%.	Output kVA %	S4L1S-F kVA @ Class H
750 / 25	200V	50%	34%	135kVA
900 / 30	240V	60%	44%	177kVA
1000 / 33	264V	66%	51%	204kVA
1100 / 36	288V	72%	58%	232kVA
1200 / 40	320V	80%	68%	272kVA
1300 / 43	344V	86%	76%	303kVA
1400 / 46	368V	92%	84%	336kVA

Speed / Hz	Voltage L-L	%.	Output kVA %	S4L1S-F kVA @ Class H
1500 / 50	400V	100%	100%	400kVA
1600 / 53	424V	106%	104%	415kVA
1700 / 56	448V	112%	113%	451kVA
1800 / 60	480V	120%	125%	500kVA
1900 / 63	504V	126%	135%	538kVA
2000 / 66	528V	132%	142%	577kVA

The nominated type of alternator must have an excitation system suitable for the rigours of operating over a speed range. Consult the Application Engineering for assistance, by emailing applications@cummins.com.

OVER SPEED OPERATION

With regard to over speed, the identified design criteria are for the rotor assembly to have a proven design capability to safely operate for a short duration under abnormal operating speeds. These are identified as being within 1.2 times the maximum rated operating speed of 1800rpm - for a four-pole alternator – which identifies a designed short term, therefore abnormal, operating speed of **1.2 x 1800 = 2160rpm.**

The rotor assemblies for STAMFORD alternators are tested, as part of the manufacturing process, for over-speed performance against compliance with Marine Classifying Society Rules, along with NEMA MG1 Part 32, where there is the requirement for 1.25 x rated speed. Against a reference rated speed of 1800 rpm, this is **1.25 x 1800 = 2250rpm.**

For AvK alternators operating over speed, contact the Application Engineering, by emailing applications@cummins.com.

The ‘pass’ criteria levels are as stated within IEC60034-1 and NEMA MG1 Part 32, and are based on the duration of the over-speed condition being for a minimum of 2 minutes. By interpretation, this means the alternator must not run at over speed for longer than 2 minutes.

Special Applications

If a Generating Set with four-pole alternator is to be used in an application that will involve running at continuous speeds in excess of 1800 rpm, then a standard production alternator may not be compliant with the inferred safety associated performance expectations of IEC60034-1 or NEMA MG1 Part 32. Such a situation must be considered to identify the operational over speed ratio, based on **2250rpm** / **(contractual continuous operating speed).**

If the answer identifies a ratio of less than 1.2 then unqualified claims of compliance with IEC60034-1 and NEMA MG1 Part 32 must not be made. Under such circumstances, appropriate changes to the information on the alternator's nameplate and within provided technical documentation will be required.

Whilst the above refers to engineering standards, there is also legal requirement to ensure that manufactured and sold products meet the requirements of CE Marking and this includes compliance with The Machinery Directive. Here the responsibility is placed on the manufacturer to ensure that, as far as is possible, any supplied component for incorporation within a complete equipment package will perform safely at the contracted operational condition and not be at risk of failure or causing damage, or injury, under identified short term abnormal operating conditions.

Commercial Discipline

Before a four-pole alternator can be offered for use at a speed greater than that typically associated with a 60Hz (1800rpm) Generating Set, the above route for due consideration of ensuring safe operation must be undertaken.

If the proposed application cannot be satisfied within the above guidance rules, then the Application Engineering must be contacted to discuss the design, manufacturing and in-service risk implications. This route should initiate special considerations and an associated risk assessment process, which is likely to identify the need for a specially prepared and so tested and certified rotor assembly; an example being a Hydro-Power application.

Critical Speed

Some specifications ask for critical speed to be twice the over-speed test value. Cummins Generator Technologies are unable to meet customer requirement for alternator critical speed at twice the over-speed test value. AvK and STAMFORD alternators are designed to perform within the following criteria:

STAMFORD 2-pole alternators: Critical speed is 4680rpm.

STAMFORD 4-pole alternators with a rotor lamination diameter up to 550mm: Critical speed is maximum nominal speed x 1.3. (1800rpm x 1.3) = 2340rpm.

AvK and STAMFORD 4- pole alternators with a rotor lamination diameter of 550mm or above: Critical speed is maximum nominal speed + 300rpm. (1800rpm + 300rpm) = 2100rpm.

For guidance on the critical speed of other AvK and STAMFORD alternators, consult the Application Engineering. Contact applications@cummins.com.