Generator Technologies

Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 046 – Alternator Operating Voltages

ACCEPTABLE VOLTAGE RANGES

Alternators incorporate a stator winding that is designed to optimise the available active materials against an identified electrical output. To achieve optimum performance from a winding design, the ideal situation is to operate the alternator at an identified kVA level of electrical output at a specific voltage and frequency (V & Hz).

There are just two operating frequencies worldwide, 50Hz and 60Hz. There are many countries around the world that operate at different voltages. Therefore; in the real world, only operating an alternator at its ideal specific voltage and related frequency (Hz), introduces unacceptable constraints to Generating Set manufacturers.

The alternator's electro-magnetic designer (emd) must be realistic and consider a 'real-world winding design' that enables the alternator to operate over a bandwidth range of voltages at each frequency (Hz). Even so, this bandwidth is limited to something like +/- 8%, about the mid-point 'ideal' output voltage.

If it becomes necessary to force the alternator to operate at a voltage level outside this designed bandwidth, then the stress must be mitigated by introducing a de-rate factor to the alternator's designed and published rated output kVA.

To cope with the wide variety of combinations of voltage and frequency used in different national systems, every alternator in the STAMFORD and AvK ranges has several different winding designs.

STATOR WINDING DESIGNS

The electro-magnetic designer needs to achieve good performance levels over several performance parameters. The emd must design to make most effective use of active materials in terms of cost against output kVA, at the best possible operating efficiency, with low reactances to provide good load acceptance and motor starting.

The electro-magnetic designer must create individual winding designs that will have a voltage range specific to a worldwide regional requirement and consider the capability of the alternator winding to be able to operate at either 50Hz or 60Hz.

Consider the most commonly manufactured alternator that is designed to offer an output to suit the standard 3 phase, 4 wire systems used in Europe at 50Hz and in the USA at 60Hz. Such a winding design is the standard winding on both STAMFORD and AvK alternators. On STAMFORD alternators, this standard winding is given a number: 311 for a winding with 12 leads out to the terminal box and 312 or 12 for a winding with 6 leads out to the terminal box. This standard winding is designed to fulfil the above criteria and is designed to operate at either a European 50 Hz, or a North American 60Hz. It is no coincidence that Europe's 50Hz and the USA's 60Hz voltages have a proportional correlation based on the 5 : 6 relationship, as follows:

50Hz.	317	347	367	**380**	**400**	**415**	440
				:	**:**	**:**	
				Designed Range			
				:	**:**	**:**	
60Hz	380	416	440	**460**	**480**	**498**	

The above comparison shows that attempting to operate a standard winding at 380V, 60 Hz, (as used in UAE and Brazil) results in the alternator operating way outside its designed operating range and as a result, will have significantly impaired performance when considered against its normal capabilities, when operating within its designed range.

To reiterate a point made previously, it is for all the above-mentioned reasons that STAMFORD and AvK alternators are offered with various winding designs, each having a specific output designed to be suitable for a particular region and each offering the expected optimum performance within the quoted voltage range. The following table shows the commonly used voltage and frequency combinations:

Voltage	Frequency Hz	Connection	STAMFORD Winding Number 12 end / 6 end
380 / 400 / 415 / 440	50	Series Star	311 / 312 / 12
660 / 690	50	Series Star	25 / 26 / 65
440 / 460 / 480	60	Series Star	311 / 312 / 12
380 / 400 / 416	60	Series Star	14 / 13
600	60	Series Star	17 / 07

Many winding designs are available for both STAMFORD and AvK alternators. For AvK alternators, the winding designs are not numbered, but referred to by their nominal voltage and frequency. For STAMFORD alternators, each winding design has a specific winding number.

WINDING CONNECTIONS

The table below lists the most commonly requested output voltages and correlated frequency. It includes the STAMFORD winding identification numbers. A winding is normally designed for use at either 50Hz or 60Hz, but has an alternative voltage range at the other frequency. Each winding has an operational voltage range in terms of maximum and minimum output voltage levels, with a Series Star or Star connection. It must be noted that when a particular winding design is used, that given type of alternator's output kVA level may not be the same as for the standard winding design (STAMFORD Winding 311 or 312/12). Also, the output kVA level will change from the nominal level when the voltage is close to the maximum or minimum voltage in the range. Refer to the alternator's published technical data for the output kVA rating at a particular voltage.

International engineering standard IEC60034-1 identifies the acceptable voltage range for a winding as +/-5% and points out that a de-rate is required if a rotating electrical machine is operated outside this bandwidth.

Winding	50Hz			60Hz			Ends
Number	Min. Volts	Nom. Volts	Max. Volts	Min. Volts	Nom. Volts	Max. Volts	Out
05	192	240	254	230	288	305	4
06	160	200	212	192	240	254	4
311	332	415	440	398	498	528	12
312	332	415	440	398	498	528	6
7	400	500	530	480	600	636	6
17	400	500	530	480	600	636	12
13	277	346	367	332	415	440	6
14	277	346	367	332	415	440	12
18	368	460	488	442	552	585	6
20	294	367	389	352	440	466	12
25	552	690	731	662	828	878	12
26	552	690	731	662	828	878	6

Different output voltages can be achieved by connecting the 6 or 12 leads out to the terminal box in different configurations. The voltages in the table on the previous page are supplied when the winding is connected in Series Star (12 leads) or Star (6 leads). It is possible to connect the 12 leads winding in to Parallel Star or Series Delta for different voltages. Similarly, it is possible to connect a 6 leads winding in Delta (Edison) configuration for different voltages, but this must be done at the time of manufacture.

The table on the following page provides a summary of the output voltages that can be achieved from different connections. Refer to Column 1 for winding numbers for STAMFORD alternators:

Winding Number	Phase	Connection	Voltage	Frequency Hz
05	1	Star	110-120V / 220-240V	50
06	1	Star	110-120V / 220-240V	60
311 (12 wire) / 312 (6 wire)	3	Star	380-440V	50
	3	Star	416-480V	60
	3	Delta	220-254V	50
	3	Parallel Star	208-220V	60
	1	Edison Delta	110V	60
	3	Edison Delta	220V	60
14 (12 wire) / 13 (6 wire)	3	Star	380-416V	60
	3	Parallel Star	208-220V	60
17 (12 wire) / 07 (6 wire)	3	Star	600V	60
	3	Star	525V*	50
25 (12 wire) / 26 (6 wire)	3	Star	660-690V	50
27 (12 wire) / 28 (6 wire)	3	Star	660-690V	60

** - Mining Applications*

The table above provides a summary of the most commonly used winding designs for low voltage outputs. There are many more winding designs and Application Engineering will assist in identifying the correct winding design for any voltage and frequency combination. Contact applications@cummins.com.

The most commonly used voltage and frequency combinations for Medium Voltage (MV) alternators are as follows:

Voltage	Connection	Frequency Hz
3.0 - 3.3 kV	Star	50
2.4 kV	Delta	60
4.16 - 4.3 kV	Star	50

The most commonly used voltage and frequency combinations for High Voltage (HV) alternators are as follows:

Voltage	Connection	Frequency Hz
6.0 kV	Star	50
7.2 kV	Star	60
10 -11.5 kV	Star	50
11 - 14 kV	Star	60

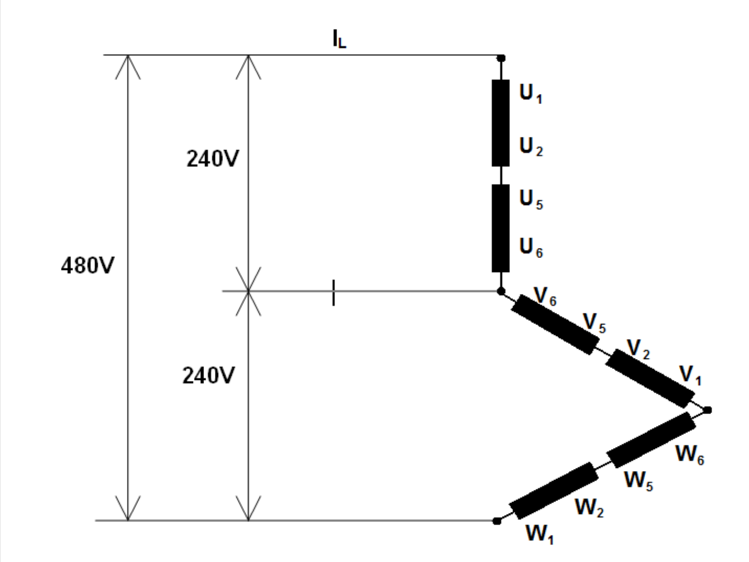
<u>Single Phase Outputs</u>

On some STAMFORD alternators, it is possible to reconnect a winding designed with 12 leads for a 3-phase output into a Double Delta configuration for a single phase output. Refer to the alternator's published technical data for the output kVA rating at a single phase voltage. More information is available in AGN154.

480V 50Hz Single Phase Rural Supply

There are remote sites that are using a 480V 50Hz single phase supply. Often, these applications are backing up/replacing the mains during a failure or maintenance works. The 480V 50Hz supply is sometimes divided to provide 240V 50Hz, supplying domestic properties in isolated areas. This is known as 'Split Phase' and is achieved by using each 240V tapping point. Split phase supplies have the potential of unbalanced loads, as this would be dependent on load requirements in the area at the time when the alternator is operating.

A 480/240V, 3 wire, rural supply, can be supplied from the standard Winding 311, by connecting into series zig-zag as shown in the following drawing:



The maximum rating available from Winding 311 in this series zig-zag connection is limited to the following.

S0/S1 range	50% of the 3-phase rating
P0/P1 range	50% of the 3-phase rating
UC 224 (S2) range	50% of the 3-phase rating
UC 274 (S3) range	50% of the 3-phase rating
S4 range	50% of the 3-phase rating
HC5 (S5) range	40% of the 3-phase rating

Example: UCI274C Winding 311 is designed for 100kVA at 415V, 3-phase, 50Hz. When connected in series zig-zag, as above, the 480V, 1-phase, 50Hz rating is 100 kVA x 0.50 = 50kVA.

NON-INTERNATIONALLY USED VOLTAGE AND FREQUENCY COMBINATIONS

There are applications such as Mining and Rubber Tyred Gantry (RTG) Crane applications that operate at non-internationally recognised voltage and frequency combinations. Many

Mining Supply Systems operate at 525V or 550V 50Hz and RTG Cranes often operate at 460V 50Hz.
Application Engineering have processes for determining the correct type and size of alternator required for these unusual applications. Contact applications@cummins.com.

LOW FLUX OPERATION

A question that is often presented to Application Engineer is; why is the rating on an alternator fitted with standard Winding 311/312/12 de-rated so much when that alternator is operated at 380V, 60Hz?

The previous section on Stator Winding Designs offers a technical explanation on why every alternator has a stator winding designed to give optimum performance at a particular voltage and frequency combination. Then technical reasons are provided as to why there is a limited capability when operating above and below this 'ideal' voltage level for the identified frequency.

Rather than a direct answer specifically for why a Winding 311/312/12 must be de-rated if required to operate at 380V, 60Hz, there are common reasons why every alternator winding design has operational limitations:

- The allowable voltage range is set by limitations of the internal electro-magnetic circuits and designed flux paths.

- The allowable current carrying capability of the stator winding is set by limitations of winding current density and the ability of the cooling circuit heat transfer characteristics.

For a fixed kVA consideration; mathematically if the voltage is decreased then the current will be increased. Needless to say the inverse relationship is true. However; there are very firm engineering limits to the voltage range +/- level over which any alternator will be able to support a fixed kVA rating.

This is quite simply the limits associated with the performance of the electro-magnetic circuits and associated limitations for the voltage range. Also current density issues for maximum allowable current level, which can be handled by the windings and therefore, cooled by alternator fan's air flow.

For example; using Winding 311 at a voltage below the published 440V at 60Hz condition 'triggers' the above identified current density technical issue. For this reason, an alternator operated at 380V, 60Hz must be de-rated by the following ratio:

(380/440) x the published 440V level of kVA rating

This simple formula takes into account the inherent limitations of the thermal heat transfer characteristic of the alternator's internal cooling circuit (fixed fan speed, blade tip diameter, therefore, cooling air volume and velocity). This is the inherent limited capability to keep the alternator's windings within designed and specified operational temperature limits, which would obviously be exceeded if the alternator's output current level was allowed to be increased in line with a technically ill-considered desire to hold fixed kVA over an impractically wide voltage range.

HIGH FLUX OPERATION

A typical example of a high flux operation is the need for 460V at 50Hz; most commonly required for RTG Crane applications. This voltage level is based on the knowledge that electrical equipment manufacturers of induction motors, lighting, etc, would not have a standard product range for this high 50Hz voltage. It is further confirmed by experience that some Variable Speed Drive (VSD) motor control units, especially in the Far East area of the world, use this voltage to power the VSD systems used on RTG Cranes.

At 460V, 50Hz the alternator's excitation is high, consequently the working flux level is high. This results in the stator lamination steel running at correspondingly high magnetic flux levels, which cause the stator lamination pack to run hot. In fact, there is a risk that the resulting high stator core pack temperature will damage the stator insulation slot liner.

Looking at a typical example; in the case of the HCI634J Winding 312, 460V = 111% flux level, and at this 'Hi-flux' the alternator requires 50% more excitation current – at no load – than the designed ideal 100% flux level at 415V, 50Hz.

To take into account this high flux and associated operating temperatures, the alternator must be de-rated. For a flux level of 111% a reasonable de-rate is between 20% and 25% below the normal 415V Class H temperature rise continuous rating.

In addition, the characteristics of load the alternator is to support must also be considered. If it is a VSD or Uninterruptible Power Supply (UPS), therefore a Non Linear Load, therefore with harmonic current and voltage distortion, this will add to the overall heating effect within the alternator, and then an even greater de-rate is required.

Looking again at our typical example; in the case of an RTG Crane, the 'Duty Cycle' of the load characteristics is very variable as hoist, trolley, and travel, each accelerate, and then run as individual drives or as combinations of operating drives. This means that the actual heating effect within the alternator of this very variable load is not a real 'continuous' problem.

A further consideration for an RTG application is the fact the alternator has been chosen to offer a low source impedance supply to ensure minimal harmonic voltage distortion whilst supporting the harmonically distorting VSD Non Linear Loads. To achieve this, it will mean that the alternator will be operating at a greater loading level than its full continuous 'thermal rating', and coupled to an engine that could not support the full thermal rating.

If the example HCI634J Winding 312 alternator is to be used for an RTG application, then there will not be a service problem for the alternator to operate at 460V, 50Hz, and have a name plate rating of 20% less than its normal 415V 50Hz continuous Class H temperature rise continuous industrial rating. Therefore 1000 x 0.8 = 800kVA is an acceptable nameplate rating at 460V 50Hz. If however; the alternator is expected to run at 460V, 50Hz continuously supporting a steady state industrial ‘prime’ type load then we may have to consider a 25% to 30% de-rate and therefore nameplated accordingly.

This is obviously a risk assessment exercise that Application Engineering are fully accustomed to. Contact applications@cummins.com to request assistance in determining the correct type and size of alternator required for these unusual applications.