Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 045 – Alternators for Parallel Operation

MAINS GRID SYSTEMS – SUPPLY NETWORKS

Over the last fifteen years or so, market trends, often encouraged by government policies, have created a proliferation of privately owned generating plants connected to the Mains Grid System – Supply Network. This in-house generation capacity has been encouraged by de-regulation and de-centralisation of state run electrical supplies and further encouraged by favourable tariffs offered for ‘interruptible power supply contracts’. As a result, large numbers of small generating capacity Generating Sets are now operating and connected to the mains supply for co-generation, peak lopping, UPS etc. It follows that equipment suppliers must recognise the implications of these market trends and cater for them adequately.

More recently, there has been the introduction of specific requirements that power generation equipment packages must meet when connected to a Mains Grid System – Supply Network. These are known as Grid Codes and in many European countries they are contractual and legally binding. There are also drives in other parts of the world, particularly in North America and Australia, to follow this same approach.

Weak Mains Grid Systems - Supply Networks

Weak Mains Grid Systems can occur in areas of limited generation capacity or remote sites at the end of a long transmission line, where the supply voltage and frequency will be affected by the behaviour of large switching transients and interruptions of the mains supply. Weak grid systems are known to be subject to sudden and brief interruptions known as ‘Loss of Mains’ and/or ‘Micro Interruptions’. Typically, the voltage may fall sharply during one half of one cycle and the frequency may slow down. Then, within the next cycle the voltage and frequency will recover. The effects of these are similar but the duration varies significantly and severe overloads can occur on the alternator. Each occurrence will cause mechanical and electrical stresses on the insulation system, as a result of the high current flows induced. It is the repetitive nature of these interruptions that damages the alternator's insulation system and may eventually lead to premature failure.

All grid systems can also suffer from other problems such as bad synchronising, lightning strikes and other voltage transients, commonly known as 'spikes'. Even suppression of lightning 'strikes' can still result in high voltage 'spikes' imposed on mains signal. Where spikes are a common occurrence, adequate suppression is required to protect the Generating Sets, in line with current best practices.

SUITABLE ALTERNATORS

Cummins Generator Technologies have developed a range of STAMFORD alternators for Co-Generation (CG) and Embedded (PE7) applications, where the utility mains voltage and frequency deviate repeatedly in what is considered to be a 'weak grid'.

The stators in these alternators incorporate symmetrical, perfect lap windings, which generate a more balanced voltage and achieve a more even temperature distribution around the stator slots and overhangs. In addition, they incorporate enhanced materials to provide significantly greater insulation strength.

The CG and PE7 alternators are fitted with the PMG powered AVR, with optional three phase RMS sensing. Cummins Generator Technologies recommend the use of power factor control, excitation monitoring and diode failure detection for all embedded applications. The especially designed alternators are design to operate with supplementary products to meet these needs - Power Factor Controller (PFC3), Excitation Loss Module (ELM) and Diode Failure Detector (DFD). In addition, these alternators can be supplied with Current Transformers for Differential Protection and Measurement. Temperature sensing is available via RTDs in the windings and bearing housings. Droop Current Transformer is also recommended for equal load sharing between the paralleled Generating Sets.

Cummins Generator Technologies have now taken these alternator designs one step further to ensure STAMFORD S4L1G, HCG5 (S5L1G), S6L1G, PEG7 (S7L1G), LVSG80 (S8L1G/S9L1G) alternators meet the increasingly stringent requirements of certain Grid Codes. These grid-compatible products are manufactured with additional bracings at the stator winding overhangs and snubber resistors are fitted to the rotor assembly, to protect the rotating diodes from voltage spikes. These products are used with either the MX type AVR or the digital AVR (such as DM110, Unitrol 1010) along with the protection modules mentioned above. The digital AVRs have already incorporated the power factor control function, which must be activated through the software.

Application Engineering are available to offer guidance on the size and design of any alternator – STAMFORD or AvK – required to meet particular Grid Codes on specific Mains Grid Systems – Supply Networks. Refer to AGN 165 – Parallel Operation with Mains grid Systems. For further assistance, contact applications@cummins.com.

Alternator Ratings for Parallel Operation

All low voltage STAMFORD and AvK DSG alternators are manufactured with a Class 'H' insulation system. Low voltage STAMFORD and AvK DSG alternators that are operated in parallel with a mains supply though, should not be operated at a rating above the Class 'F' temperature rise continuous industrial ratings, as specified in the alternator's Technical Data Sheet. This rule is determined after careful considerations of the mechanical, electrical and thermal properties of the alternator's insulation system.

All winding assembly insulation systems are comprised of a number of different materials, carefully selected as fit-for-purpose to ensure chemical compatibility with the challenge of ensuring mechanical strength and tear resistance. A very important consideration is the dielectric strength of the insulation system in terms of withstanding the electrical potential differences encountered under rated voltage level, as well as the additionally imposed voltage levels (up to +/- 10% of rated voltage) resulting from the behavioral characteristics of the connected electrical load, within the case of embedded operation and the instability of the host electrical system.

As the winding assembly's operating temperatures increase, the mechanical properties alter as the insulation system changes from 'rigid' to a more 'plastic' behavior and the electrical insulation properties change as the dielectric strength reduces. Fundamentally, the winding assembly 'withstand' properties become less capable. Furthermore, the time spent operating at high temperatures reduces the insulation system's life expectancy, due to thermal degradation.

There are 'rules of thumb' around how the insulation system's properties change with temperature:

- Mechanical strength. Compared with strength at room temperature, it will be reduced to some 50% once the winding assembly is operating at 120ºC and will only be 33% at 180ºC.

- Electrical dielectric strength in terms of V/micron. Compared to room temperature level, it will be reduced to 50% at 140ºC and some 33% at 200ºC.

The theoretical life expectancy of an insulation system is based on UL data, which uses the following theoretical 'half-life' index:

- Class 'H' insulation system has a total temperature of 180ºC. When operated at the maximum continuous Class 'H' temperature rise rating, then 'half-life' is expected to be 20,000 Hours.

- When the Class 'H' insulation system is operated at the continuous Class 'F' temperature rise rating, then 'half-life' is expected to be 120,000 Hours.

- When the Class 'H' insulation system is operated at the continuous Class ‘B’ temperature rise rating, then ‘half-life’ is expected to be 640,000 Hours.

For further information on the life expectancy of the insulation system, refer to AGN021 – Alternator Life Expectancy.

There are other factors that affect the performance and life expectancy of insulation systems. Thermal cycling and the resulting expansion / contraction, as well as surface contamination are contributing factors. The operating conditions of transient changes to the load voltages and currents will impose magneto-motive-forces (mmf) torques within the winding assembly, which may cause rupture at a section of insulating membrane and thereby, introduce a failure mechanism which may, or may not, be immediate.

When applying a STAMFORD or AvK alternator to an embedded application and so connecting it to a live dynamic host supply network (Mains Grid System), the Generating Set will inevitably be subjected to imposed transient and momentary stress as the host network behaves in sympathy with the connected loads characteristics and the response of the inherent base power generation equipment. One sure way to mitigate some of this stress is to ensure the embedded Generating Set is not running too hot and by that, engineers experienced in the application of embedded power generation schemes, ensure their design package operates within the alternator windings, at temperatures of typically, 110ºC to 125ºC and ensure they NEVER exceed the Class ‘F’ temperature rise continuous rating limit.

ALTERNATOR WINDING PITCH AND STAR POINT CONSIDERATIONS

Special considerations must be made with regards to the alternator’s winding pitch and star point connections when paralleling Generating Sets. Winding pitch is defined as the ratio of stator coil span to the pole pitch. 5/6th pitch windings suppress 5th and 7th voltage harmonics but enhance the ‘triplens’ (3^{rd,} 9th etc...). 2/3rd pitch windings suppress the ‘triplens’ but enhance the 5th and 7th voltage harmonics.

If an alternator with 2/3rd winding pitch is paralleled to an alternator with 5/6th winding pitch, there will be differences in the harmonic ‘structure’ of the voltage waveforms. These electrical ‘potential differences’ will result in circulating currents between the two alternators, in sympathy with whichever waveform – at that instant - has the highest ‘electrical pressure’.

Parallel operation of alternators with similar 2/3rd winding pitch are the best for supporting three phase, four wire, connected installations with mixed 3-phase and 1-phase loads. This is because the 2/3rd winding pitch design does not generate triplen harmonics. Therefore, there is no inherent characteristic from the generated voltage waveform to cause high neutral currents in the connected distribution system.

Parallel operation of alternators that have been manufactured with a similar winding pitch of other factors (e.g. 5/6th, 7/8th, full pitch etc) should not necessarily result in circulating current problems due to generated voltage waveform harmonic content. However, such systems can be more susceptible to the load's current consuming characteristics and this may result in a distribution system with high neutral currents.

The actual level of circulating current is a complex issue. It will depend on the interconnecting / distribution system impedance's and will also be very susceptible to the characteristics of the connected site load being supported by the Generating Sets. Interconnecting the alternator's stator windings' star points will also change the characteristics of the circulating currents, both between the alternators and the level of 'Neutral current' within the supplied distribution system.

Therefore, consider if the site load can be correctly supported and the site's electrical protection system will still function correctly, without the two 'dissimilar' alternators having their star points interconnected. It figures that if the site loads single phase equipment can be supported by the fully rated neutral of just one alternator, then do not interconnect more Generating Set Neutrals together if this promotes unnecessary circulating currents around the Neutral conductor system. However, if the schemes protection philosophy is such that all-star points must be interconnected, then measurements have to be made as to the extent of the circulating currents to ensure that the alternator stator windings are not overloaded and that the site distribution systems Neutral cables are rated accordingly.

Many alternators of 2/3rd, or 5/6th pitch, are used for embedded / co-generation applications with Mains Grid Systems – Supply Networks. In most cases such alternators do not have their star points interconnected to the mains Neutral or Earth connection. In such an application the pitch factor is not an important issue.

When dealing with Generating Sets operating in parallel with a Mains Grid System – Supply Network, then understand the protection philosophy of the mains network and ensure that the bonding of any alternator star points to earth will not provide a parallel path for fault current outside the protection system's monitored fault-path.