STAMFORD | AvK ™

POWERING TOMORROW, TOGETHER

Application Guidance Notes: Technical Information from STAMFORD | AvK

AGN038 – Earthing

EARTHING REFERENCE

Legislation requires the alternator output windings [stator] to be referenced to a 'body' and this is usually 'mother earth'. The requirement to 'reference' the output windings is for the following reasons:

- In order to provide a return path for fault current resulting from connected equipment, or a distribution system, which develops damaged / exposed conductors and thereby, a means for fault current to operate over current detecting equipment or protection systems. Equipment and systems such as thermal and magnetic tripped Circuit Breaker's or suitably designed fuses.

- In order for personnel protection, in the form of RCD's, to detect leakage current that will 'return' via the protective conductor.

- In order to ensure power systems are 'referenced' to provide a solid point at earth potential and thereby stop the electrical system floating at unexpectedly high levels of potential difference above earth.

The part of the stator winding that is connected or referenced to the 'body' is then called the **Neutral**, simply because this reference point becomes the Neutral**ised** end/part of the windings.

The most commonly found referenced part of the winding is the star point of a three phase star system creating L1[U], L2[V], L3[W], N, therefore, a scheme that offers output voltages at both 3-phase and single phase.

On dedicated single phase winding systems, the most common method is to reference one end of the winding, creating L and N, where only the L is over-current protected and switched. However, there are dedicated single phase three wire systems, where the centre point of the winding is referenced, creating L1, N, L2. Here both the L lines must be protected and switched.

This connection to 'mother earth' is usually by a solid bonding for an unrestricted fault current earth return path.

There are situations where the windings are referenced to earth via a resistor, transformer, or reactor, creating a restricted fault current, return path, but these systems are only used in conjunction with a specific protective system designed around this requirement.

When considering the selection of output sockets for a Generating Set, they should be chosen with due consideration of their protecting system characteristics. Sockets can only include an earth pin for a Generating Set output supply system that has been correctly referenced. By providing an output socket with an earth pin, the user will assume that the alternator's windings have been referenced and therefore, not offering a protection system correctly designed for the use of Class 1 (non-double insulated) equipment, where exposed metallic parts must be connected to the power source and so, the 'master reference point' via the distribution system and equipment's green and yellow 'earth' lead.

If the alternator's windings are not to be Neutralised, then an un-referenced system is to be used, therefore, the output sockets must be two pin, with clear instructions that only Class 2, double insulated, equipment is to be connected.

There are situations where bonding the alternator to 'mother earth' might not be possible, or practical. It must be appreciated that to get a sufficiently low resistance connection to 'mother earth' will require a great deal of engineering skill and effort and the risk of damaging underground services must not be discounted.

The provision of temporary power supplies provided by mobile Generating Sets can be addressed by an engineered and controlled approach and is often referred to as taking all 'reasonable care' and in fact, by a process of risk assessment will result in a safe system, and so will ensure equipment and personnel protection equipment will operate should a fault occur.

The most effective and practical way to achieve a safe system is to create an 'equipotential zone'. This is achieved by ensuring the alternator's windings are referenced to an identified 'earth' terminal at the Generating Set and this is, in turn, connected to the Generating Set metalwork. This 'earth terminal' then becomes the 'master' terminal for the connection of the distribution system's green/yellow protective conductors, which are included within the distribution system's cabling.

All output sockets would then offer an ‘earth pin’ and so; each would have a referenced and protective connection to all connected electrical equipment. Now, if any connected item becomes faulty and the ‘live’ conductor becomes connected to exposed conductive surfaces the distribution system’s protection devices will be activated and that circuit ‘disconnected’.

It becomes the responsibility of any person connecting electrical equipment to this supply to have current certification of Portable Appliance Testing [PAT] for each connected item.

The above suggested ‘equipotential zone’ protection system can be considered as an engineered solution for such events as mobile fairgrounds, and outdoor field events, perhaps involving marquees: but by their nature, events at a location for a few days only.

Similarly, there may be an instance where the Generating Set is being used a distance above ground level on a civil engineering site. Under such temporary conditions, it could be considered acceptable to create an equipotential zone for the work area by interconnecting all exposed conductive metal work to the Generating Set’s nominated reference point. That could be the building sites structure.

In a very temporary situation, such as a Generating Set being used in conjunction with the fitting of a sign to the outside of shop, ‘all reasonable care’ should be taken to ensure good safe working practice is used in the work area and the work area cordoned off from non-essential personnel.

Note: RCD’s will only work on correctly ‘referenced’ systems.

There are numerous methods of reference to provide a safe operating supply system and, therefore; the alternator manufacturer will supply all alternators with no connection between any part of the windings and the earth terminals. The Protection System and so grounding scheme must be specified by the Protection Engineer responsible for the designing of the overall electrical system into which the Generating Set is to be installed.

THE ALTERNATOR’S DESIGNED PROVISION FOR EARTH TERMINALS

The national and international engineering standards for Rotating Electrical Machines include instructions for the provision of an ‘Earthing Terminal’. The principal standard applicable to all types of Rotating Electrical Machines and thereby including A.C. generators (alternators), is IEC60034. Section 11 – Miscellaneous Requirements, Sub-Section 11.1 – Protective Earthing of Machines, outlines the requirement for earthing of machines, including STAMFORD and AvK alternators.

Specifically on every alternator, there is a need for an earth terminal to be provided adjacent to the main terminal arrangement and for electrical machines greater than 100kVA, the provision of an additional earth terminal on the frame. All STAMFORD and AvK alternators are manufactured with multiple earth terminals.

Main Earth Terminal

Within the terminal box, and so adjacent to the main terminals, there is an identified earth terminal which is bonded to the metal structure of the alternator's frame.

Additional Earth Terminal

The main frame assembly of all STAMFORD and AvK alternators is manufactured with consideration for the connection of additional protective conductors or earth conductors. The provision for an additional earth connection is provided to enable the manufacturer of the Generating Set, into which the alternator is being incorporated, to connect an appropriate size and type of earth / protective conductors.

The Owner's Manual (also known as the Installation, Service and Maintenance Manual), which is issued with every alternator, includes advice concerning the obligation the Generating Set manufacturer to provide for appropriate bonding and so provide a facility for the connection of correctly rated earth / protective conductors.

Location of the connection point for additional earth / protective conductor(s)

Specifically for STAMFORD alternators additional earth terminals are provided in the following locations:

The UC 224 (S2) and UC 274 (S3) alternators have a hole in the alternator's foot arrangement, located between the large 'holding-down' bolt holes.

The S4 and HC5 (S5) alternators have a threaded hole on both sides of the alternator, located within the foot adjacent to the foot to frame interface.

The S6 and P7 (S7) alternators have several threaded holes on both sides of the alternator, located within the foot to frame rib, at the engine end.

AvK alternators will have a number of additional earth terminals at locations on the alternator's frame that are suitable for the customer's installation. Actual locations will be decided during specification negotiations with AvK engineers.

Earth Marking

Only the main earth terminal point within the terminal box is marked with an 'earth symbol'. The additional 'frame' terminals do not have an 'earth symbol', because each Generating Set manufacturer has an individual method for use of the provided additional 'point of connection' on the frame. Their product experience and designed control of successful incorporation of alternators into their Generating Sets ensures compliance with the overall responsibility they have for supplying an equipment package with installation compliant terminations of the earthing / protective conductors, marked appropriately as part of their finished product and correct use identified within their Installations and operations manual for the Generating Set.

CONSIDERATIONS FOR EARTHING AND PARALLEL OPERATION

This section was prompted by questions relating to the required earthing method of parallel running Generating Sets.

The Protection System and so grounding scheme for any power generation network must be specified by the Protection Engineer responsible for the designing of the overall electrical system into which the alternators are to be incorporated. This is a specialist task and specific to local site requirements and conditions and therefore, definitely not an area of expertise for STAMFORD | AvK.

All STAMFORD and AvK alternators are designed and manufactured with all the output winding [stator] phase leads being brought to the alternator's output terminals and so, suitable for direct and unrestricted fault current levels, but do require due respect of the alternator's thermal damage curve. This provision of fully rated output leads and connections from a totally isolated stator winding allow any point of the output winding to be referenced to 'earth'. However, the most commonly encountered electrical schemes are based on the stator winding's being STAR connected and the star point of the output windings being Referenced and so, Neutralised, to Earth.

The majority of Protection Schemes are designed for the alternator to be incorporated into an unrestricted fault current system, with the star point being solidly bonded to earth and so, unrestricted fault current will flow - subject to distribution system and fault impedance - and so directly trip the incorporated over current protection devices.

If the Protection Engineer cannot use a solidly boded to earth protection scheme and so, must reference to ground through an 'earthing - resistor' [or transformer, or choke], then an appropriate fault current detection method, designed to 'recognise and activate' the shunt trip mechanism of a Circuit Breaking device, must be designed and then incorporated within the electrical installation.

The Protection Engineer must consider parallel fault current paths to earth and ensure that a fault current does not become distributed and diluted such that the Protection System fails to recognise a fault condition. This may require Generating Sets to be grouped into zones, with only one point of a zone bonded to earth. But such schemes are a specialist area for a qualified and experienced Protection Engineer to consider, along with the site earthing 'connection' impedance introduced by installed local earth matt and/or rods and local soil /earth/ground resistivity values.

The decision whether to interconnect all alternator star points must be based on consideration of the characteristics of the connected load. If high levels of single phase loads are to be supplied then many Generating Sets may be required to share the total single phase load. In such a case, the star points of the required alternators will need to be interconnected with a Neutral cable. This should not be confused with the totally different situation of connecting individual star points to earth with a green/yellow non-current carrying protective 'earth' conductor.

If the alternators are of a different design, or even more critically, of a different stator winding coil pitch [e.g.: not all 2/3rd's or 5/6th etc...] then the differences in the harmonic content of the generated voltage waveform from each individual alternator will promote circulating currents between alternators and may promote a harmonic content in the current of connected loads. If the connected loads have Non Linear current 'consuming' characteristics, then problems with high levels of harmonic distortion - current and voltage - may well require careful consideration, this being an important issue any time a NLL is to be supplied by an alternator.

Different sizes of Generating Sets operating in parallel, suggests different designs of Generating Set. Therefore, the above comments regarding circulating current must be considered. It can be categorically stated that all STAMFORD alternators with an output rating of up to 3MVA are manufactured with a 2/3rd winding pitch. AvK alternators are mostly 5/6th pitch, although some models are available with 2/3rds pitch windings.

From experience, the current consuming characteristics of the connected loads will change the overall harmonic content of the applied voltage waveform and in turn, any observed circulating current with parallel Generating Sets operating at No-load, will change to a different level - usually less - as the percentage of load is increased. Providing the Generating Set’s rated current is never exceeded then circulating current as an individual consideration will not be an issue for the alternators.

Different sizes of Generating Sets will successfully operate together in parallel providing: the Quadrature droop setting of each alternator has been correctly set to ensure proportional kVAr sharing and engine governors have been correctly set to ensure proportional kW sharing.

The Synchronising of the Generating Sets must be a controlled - and preferably automatic - situation of voltage matching to within +/- 0.5%, phase rotation matching within +/- 10 elect degrees and frequency matching within 0.1Hz, prior to the inter-connection closing.

ALTERNATOR EARTH IMPEDANCE

Unlike a transformer, an alternator has a dynamic control [excitation] system that radically affects its performance under gross overload and short circuit - fault conditions. In fact, the type of excitation system can mean the difference between the alternator being able to support a sustained short circuit current of typically some three times rated current, or a situation of zero sustained short circuit current.

A transformer has an inherent design characteristic and its performance under fault conditions will be a product of its design in conjunction with the source impedance of its supply network. Therefore, it is correct to discuss and consider the impedance of a transformer to identify its fault contribution.

However, an alternator’s fault contribution is established by consideration of its various reactance values and time constants. The impedance of the distribution network connected to the output terminals of both a transformer or a alternator must also be established, as these will have a considerable effect on the resulting fault current levels and voltage levels at points within the distribution system between the ‘power source’ and fault.

The performance data relating to an alternator subjected to a fault condition; L-L-L 3ph fault, or L-L 2ph fault, or a L-N 1ph fault, is incorporated within each individual alternator's Technical Data Sheet, identified in graphical form as the 'Short Circuit Decrement Curve'. This curve displays the performance from time zero of fault occurring, out to some ten seconds of fault duration. The Decrement Curve shows the performance of an alternator fitted with an excitation system capable of supporting a sustained fault current. In STAMFORD alternator terminology, this would be identified as Series 3 excitation system, and consists of any MX type AVR and a PMG being fitted to the alternator, outboard of the NDE bearing.

When an AS or SX type AVR is fitted the Decrement Curve will be unchanged from time zero (moment of fault occurrence) out to the lowest point of the fault current curve, but now instead of rising to a sustained level, the curve continues to fall – following the dI:dT falling rate of the graphical arc shape - to ZERO amps.

Notes 1 and 2 on the Decrement Curve in the datasheet provide guidance for identifying the curve shape for various operating voltage levels and types of fault conditions.

For further information, refer to AGN005 – Fault Currents and Short Circuit Decrement Curves.

When choosing a suitable Circuit Breaker [CB] for the alternator / Generating Set – because the Generating Set may be offered at a lower rating than the alternator's actual designed capabilities - the Decrement Curve should be used, along with the alternator's Thermal Damage Curve. Together these identify the allowed duration of an expected over / fault current condition.

Jointly considering the Decrement Curve and CB tripping-curves, enables assurance that a 'trip' will occur and then consideration of the identified trip time against the alternator's Thermal Damage Curve to ensure 'disconnect' will occur before permanent thermal degradation occurs to the alternator's winding assembly. It is also advisable to consider the alternator's overload capability, as this provides information about the alternator's performance under gross overload conditions, rather than outright short circuit fault conditions.

For further information, refer to AGN035 – Overload and Fault Protection.

For a complete system study, the alternator's reactance values, time constants, and winding resistances may also be required. This information is included within the alternator's Technical Data Sheet.
It is possible to calculate a value for Alternator **Earth Impedance (Ze)** from data sheet information and this enables a value for the alternator to be included in a calculation to identify the impedance value for the complete network.

Alternator source impedance (Ze) is based on the alternator's leakage reactance X_L. This reactance needs to be changed into ohms by establishing the 'Base Impedance'

$$\text{Base Impedance} = \frac{V_{L-L}^2}{(\text{kVA} \times 1000)}$$

X_L in ohms = Base Impedance x X_L in p.u.

$$Ze = \sqrt{(X_L\ \text{Ohms})^2 + (\text{Alternator L-N Stator Resistance} + \text{External Earth Loop Cable})^2}$$

Example:

Alternator Type: S4L1S-C Winding 311, rated at 250kVA, 415V, 3ph, 50Hz.
X_L = 0.08p.u.
Alternator stator resistance, L-N = 0.018 Ohms

$$\text{Base impedance} = \frac{415^2}{250 \times 1000} = 0.6889\ \text{Ohms}$$

X_L in ohms = 0.6889 x 0.08 = 0.055 Ohms

$$Z_E = \sqrt{0.055^2 + (0.018 + \text{External Earth Cable Loop})^2}$$

Z_E therefore includes the value of an external earth loop resistance which has to be established with knowledge of the proposed Generating Set's installation site.

Leakage Reactance X_L – An Explanation

The use of X_L in the calculation provided above has prompted comments and so for further technical considerations, the following outlines the result of the above exercise.

The sphere of technical consideration for the electrical system for which Ze is being identified must take into account the impedance of the actual 'earth fault' condition. If the fault is a low impedance, therefore resulting in high fault current level the consequence of which results in virtually zero system voltage, the alternators 'response' must be considered using reactance parameters associated with saturated iron circuits and their associated magnetic circuits. If the fault condition is of a relatively high impedance, resulting in the alternator response being within what would be considered as a momentary overload condition - say 150% rated current levels - but allowing the alternator to maintain say, in excess of 80% rated voltage, then no operational levels of severe saturation are encountered and so not requiring appropriate - but different - reactance parameters to be considered.

Just to clarify, the method we advocate involves the use of X_L (leakage reactance), which we consider to be appropriate for a fault condition within a distribution system; therefore more in line with a level of momentary overload, rather than very low impedance – virtual short circuit - occurring very close to the alternator's output terminals.

The table on the next page provides examples of the component values, which constitute the total Z_E. Note that the biggest influence is the distribution system cabling.

Typical values to enable the calculation of the generators contibution towards total system Ze Based on 415V three phase 50Hz.					Typical system Ze *If cable loop Z is 1.0 ohm*
Gen. kVA	**L-N ohms**	**XL pu. typical**	**Gen. Base Z**	**XL in Ohms**	
25	0.214	0.07	6.8890	0.4822	1.31
50	0.13	0.07	3.4445	0.2411	1.16
100	0.06	0.07	1.7223	0.1206	1.07
200	0.007	0.07	0.8611	0.0603	1.01
300	0.012	0.07	0.5741	0.0402	1.01
400	0.0073	0.07	0.4306	0.0301	1.01
500	0.005	0.07	0.3445	0.0241	1.01
600	0.0041	0.07	0.2870	0.0201	1.00
700	0.0034	0.07	0.2460	0.0172	1.00
800	0.003	0.07	0.2153	0.0151	1.00
900	0.0025	0.07	0.1914	0.0134	1.00
1000	0.0022	0.07	0.1722	0.0121	1.00
1250	0.0017	0.07	0.1378	0.0096	1.00
1500	0.0013	0.07	0.1148	0.0080	1.00
1750	0.0009	0.07	0.0984	0.0069	1.00
2000	0.0008	0.07	0.0861	0.0060	1.00

Comment........Note how the cable impedance dominates the value of Ze, above 200kVA the gen's contribution is negligible

ALTERNATOR STATOR CAPACITANCE TO EARTH

Capacitance is measured with the Star point disconnected from Earth and from each Phase to the Frame (Earth). Also, with all three phases shorted together and measured from this point to Earth.

STAMFORD UC 224 (S2) and UC274 (S3) Alternators:

U - Earth	-	0.017 micro Farad	(0.021 X 10-6)
V - Earth	-	0.017 micro Farad	(0.021 X 10-6)
W - Earth	-	0.017 micro Farad	(0.021 X 10-6)
3 Phases	- Earth -	0.051 micro Farad	

STAMFORD S4 Alternator:

U - Earth	-	0.021 micro Farad	(0.021 X 10-6)
V - Earth	-	0.021 micro Farad	(0.021 X 10-6)
W - Earth	-	0.021 micro Farad	(0.021 X 10-6)
3 Phases	- Earth -	0.063 micro Farad	

STAMFORD HC5 (S5) Alternator:

U - Earth	-	0.028 micro Farad	(0.028 X 10-6)
V - Earth	-	0.028 micro Farad	(0.028 X 10-6)
W - Earth	-	0.028 micro Farad	(0.028 X 10-6)
3 Phases	- Earth -	0.084 micro Farad	

STAMFORD S6 Alternator:

U - Earth	-	0.045 micro Farad (0.045 X 10-6)
V - Earth	-	0.045 micro Farad (0.045 X 10-6)
W - Earth	-	0.045 micro Farad (0.045 X 10-6)
3 Phases	- Earth -	0.135 micro Farad

STAMFORD P7 (S7) Alternator:

U - Earth	-	0.050 micro Farad (0.05 X 10-6)
V - Earth	-	0.050 micro Farad (0.05 X 10-6)
W - Earth	-	0.050 micro Farad (0.05 X 10-6)
3 Phases	- Earth -	0.150 micro Farad

STAMFORD P80 Alternator:

U - Earth	-	0.037 micro Farad (0.037 x 10-6)
V - Earth	-	0.037 micro Farad (0.037 x 10-6)
W - Earth	-	0.037 micro Farad (0.037 x 10-6)
3 Phases	- Earth -	0.110 micro Farad

For capacitance measurement for all other STAMFORD and AvK alternators, contact applications@cummins.com.

stamford-avk@cummins.com

www.stamford-avk.com

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