Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 035 – Overload and Fault Protection

OVERLOAD AND FAULT CLEARING DATA

When electrical engineers consider an electrical system into which a Generating Set is to be incorporated, one aspect of their considerations will be the electrical protection requirements. This requires gaining an understanding of the characteristics of the Generating Set in terms of sustained, temporary and transient overload conditions.

It is not the intention of this AGN to describe how such complex considerations are undertaken, rather to offer a fundamental comment on the process that must be followed and the helpful documents the alternator manufacturer can provide.

The Technical Data Sheets (TDS) for alternators include a Short Circuit Decrement Curve and this provides the engineer responsible for selecting the Generating Set's circuit breaker with sufficient technical information for considering the prospective fault current levels over time for the various fault condition scenarios (L-L-L, L-L, L-N) the alternator may encounter.

A Thermal Damage Curve is available upon request and this provides details of the alternator's capability to provide steady state levels of overload out to transient fault clearing current levels displayed against allowable time.

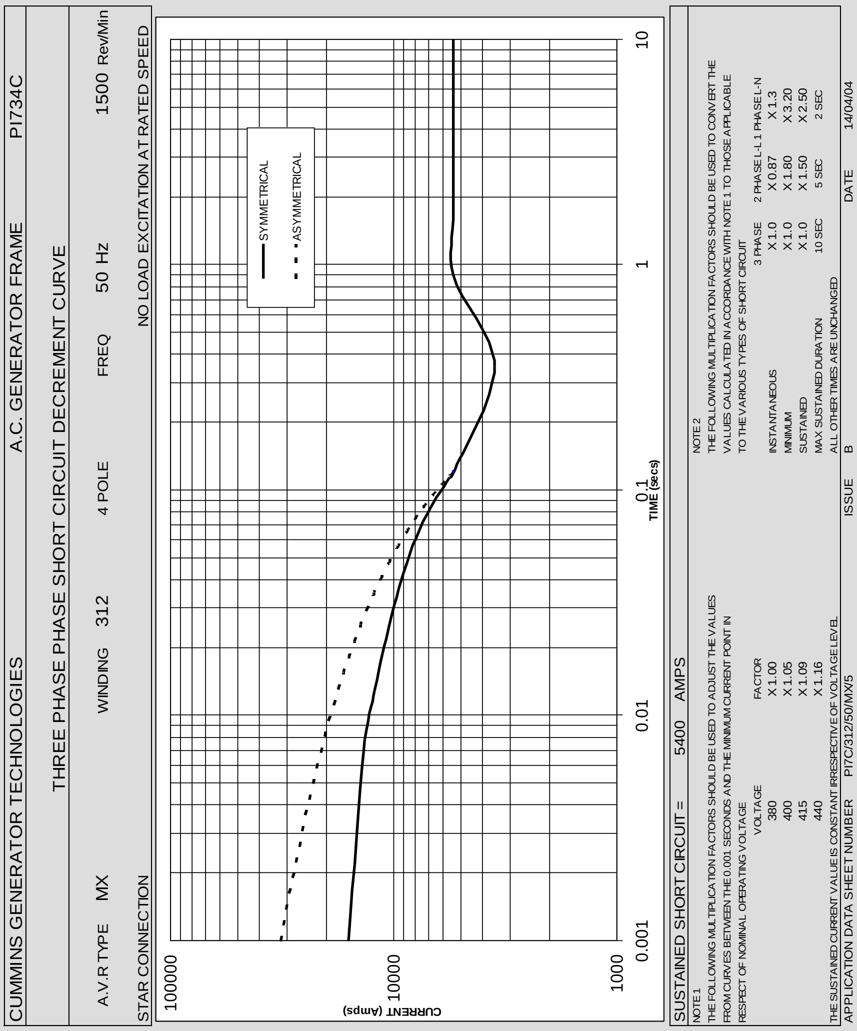
Both the above documents display the balanced load or fault conditions, with guidance notes to advise how to consider a two phases or single phase fault condition.

The decrement curve displays fault current levels from time zero out to 10 seconds. By due consideration of the decrement curve it is possible to gain an appreciation of the incremental values of fault current level against time and this can be transposed by the electrical engineer into cycle by cycle level if so desired. For further guidance on decrement curves, refer to AGN005 – Fault Currents and Short Circuit Decrement Curves.

The thermal damage curve purposely stops at 8 times rated current, a condition that will only be encountered under a single phase fault of virtually zero impedance. The note included on the thermal damage curve advises that it is imperative to ensure the disconnect time for fault conditions must be within the graphically displayed current against time, in order to avoid initiating permanent damage, which would result in the thermal degradation of the alternator’s insulation system.

The disconnect times are achieved by the engineer responsible for selecting a circuit breaker, which has the appropriate adjustable tripping characteristics that can be set to ensure compliance with the prospective fault current levels set for tripping times within the thermal damage curve time limits.

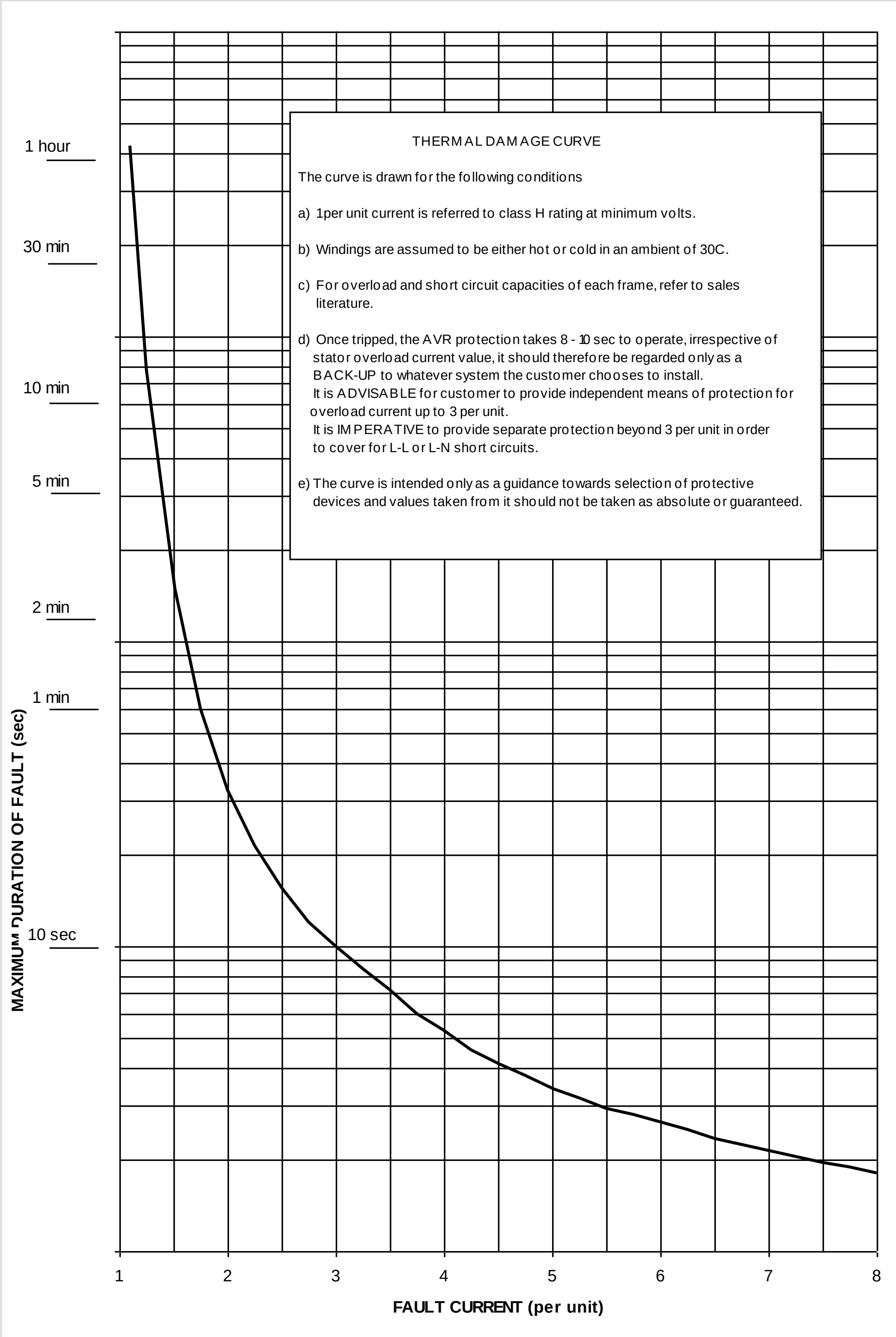
The following three pages have an example of; a Short Circuit Decrement Curve, a Thermal Damage Curve and the tripping characteristics of a typical circuit breaker.



Three Phase Short Circuit Decrement Curve

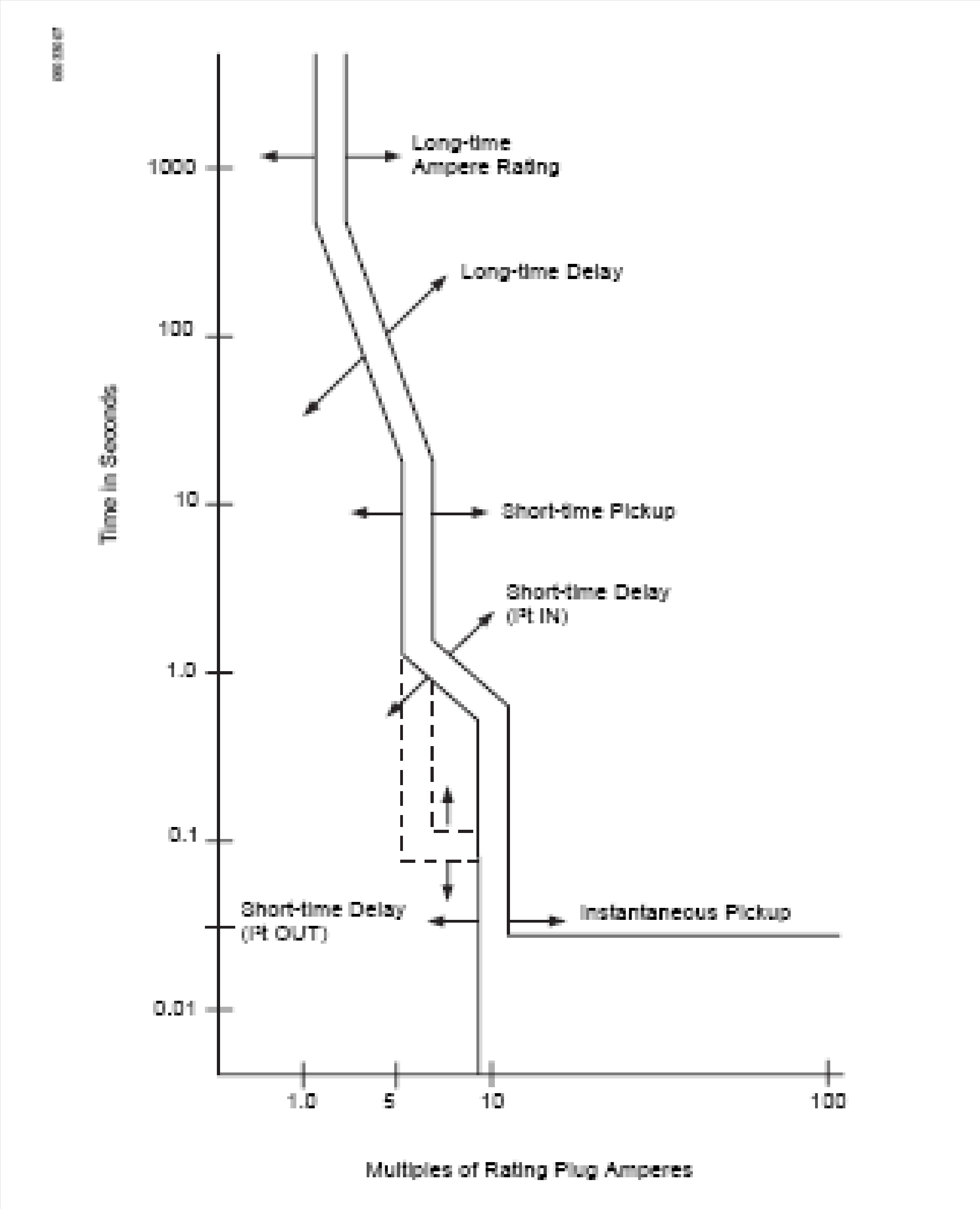
CUMMINS GENERATOR TECHNOLOGIES	A.C. GENERATOR FRAME	P7

THERMAL DAMAGE CURVE



APPLICATIONS DATA SHEET NUMBER **P7/NA/NA/NA/9/THERMAL DAMAGE**

Thermal Damage Curve



Tripping Characteristics of a Typical Circuit Breaker

FAULT CONDITION PEAK TORQUE LEVELS

Fault conditions

When a Generating Set is subjected to a short circuit fault condition, be that, L-L-L, or L-L, or L-N, or L-L-N, the alternator will behave in a manner associated with the complex magnetic fields associated with the characteristics of the type of fault. The characteristics are primarily dominated on whether the fault results in balanced or unbalanced currents flowing through the three phases of the alternator's windings. In electrical terms, these conditions are described as having: positive, negative or zero sequence components.

Furthermore, whether the fault has occurred at a moment in time that aligned with symmetrical (balanced +/-) levels in a sinusoidal pattern about the zero (centre) line, or if the fault has occurred at a moment in time associated with the generated output waveform resulting in an Asymmetrically situation, and so fully biased to just one side (eg; all + and so above) of the zero (centre) line, which in electrical terms we describe as having a dc component.

Quantifying Fault Levels

The alternator's Short Circuit Decrement Curve displays graphically the levels of current that will be generated under an L-L-L (3ph) fault conditions, and the situation under L-L and L-N can be calculated by reference to the information in Note 2 on the decrement curve sheet. The decrement curve shows both the symmetrical (solid line), and asymmetrical (dotted line) fault current levels, from the instant of the fault occurring (time zero) over the following time period of the stored magnetic energy being dissipated – fault current level falling – and eventually the merging of the symmetrical and asymmetrical curves. Then the action of the alternator's electro-magnetic field system being 'excited' and the whole excitation system being 'forced' into saturation as depicted by the steady state condition of the fault current being a stable and constant (horizontal line) level.

It is fair to assume that 99% of all 'faults' never occur at either precisely the symmetrical or the asymmetrical position, but just somewhere in between the two. As engineers, we must always consider the two extremes and then introduce an appropriate safety factor to cover a well-engineered but cost effective solution for all situations.

The duration of the peak torque level(s), decaying to a minimum and then forced up to a steady state level, can be correlated with that of the changing current levels shown on the decrement curve.

The duration of the peak fault current levels can be considered to be up to 5 milliseconds. It must be accepted that the majority of this peak torque will not be delivered through to the engine via the shaft coupling, but be a product of the alternator rotor's stored kinetic energy, identified by electrical engineers as inertia constant (H). Obviously, the coupling will be subjected to some level of transient peak torque demand during the time zero up to steady state condition and the 'typical' level considered by responsible mechanical engineers is 12 times rated torque.

It should not be forgotten that the most arduous conditions for generating mechanical forces within a Generating Set are under conditions of 'miss-paralleling', where a situation of closing the circuit breaker between the mains supply and a generator some 120 elect-degrees out of phase will result in peak transient torque levels that are some 1.3 times the transient peak Asymmetrical L-L-L fault condition.

The Technical Data Sheet for each type of alternator will contain a Short Circuit Decrement Curve and all the required parameters to consider peak torque levels from a first principle calculation.

OVERLOAD AND FAULT PROTECTION – SELF EXCITED ALTERNATORS

The ability of a self-excited alternator fitted with a SX or AS type AVR and excitation system to blow a fuse or trip a circuit breaker that has been chosen because it has a designed current rating equal to the alternator's output current rating, is often the subject of a technical discussion between Generating Set manufacturers and alternator suppliers.

The technical solution is well understood by experienced Generating Set manufacturers who consider the fundamental design principles of electrical protection systems and by so doing, ensure the electrical output of alternators fitted with SX or AS type AVR's are protected by a 'graded' or 'cascading' protection system. Thereby, the design of their Generating Sets duly considers the lack of a steady state short circuit current associated with the self-excited systems.

A self-excited system will typically blow a fuse or trip a standard Class A tripping characteristic Circuit Breaker if these protection devices have a current rating equivalent to 60% of the alternator's rated output current.

The following guidance is offered for a practical scenario:

- If a self-excited system is subjected to gross overload, then the output voltage will fall to a point that the SX or AS type AVR loses its power supply. The alternator's output voltage collapses, the fault current collapses and the Generating Set is therefore 'Self Protecting' itself and the connected faulty piece of electrical equipment.

- Even small Generating Sets are usually connected to a distribution system that incorporates 'graded' levels [cascaded levels] of electrical circuits and each circuit has a current discrimination level below the alternator's output rated current. Such an electrical circuit ensures that the Generating Set is supplying an electrical circuit with a designed protection network, which ensures only the faulty circuit activates its protection device, leaving all healthy circuits still with an electrical supply.

- If the fault occurs in the main cable from the Generating Set to the master connection point of the connected electrical distribution system, then that 'connected electrical distribution system' cannot in any case be supplied. If the self-excited alternator reaches a point of gross overload and the output voltage collapses and so the Generating Set stops giving an output, then we are already in a situation where the 'connected electrical distribution system' and load cannot be supplied until the faulty master cable has been repaired.

- Well engineered Generating Sets will have a voltage and frequency monitoring detection circuit to identify over and under situations for both voltage and frequency. This is because a supply load outside the expected +/- limits will damage the connected equipment. Once these modules detect a fault condition, they should activate a load disconnection and an engine shutdown.

PROTECTION PARAMETERS AND LEVELS

The following protection parameters and included values are based on research of appropriate technical papers, along with a technical discussion with key Generating Set manufacturers with experience of supplying, commissioning and supporting power generation packages, which are to be embedded within a mains supply (Grid) network or a multi-generator islanded power generation scheme.

The consensus of technical opinion firmly supports the need for every such application to be subjected to a thorough technical consideration prior to any contractual agreement. Furthermore, if this technical consideration becomes complex, then a carefully conducted power flow study, or computer based modelling system, must be undertaken in order to identify the operational risk of the new power generation package promoting system instability, or the risk of an inherently unstable existing electrical power system damaging the newly installed power generation package.

Protection Parameters

Voltage

The following setting levels are subjective, to the identified variations for the host Mains Grid network, and therefore appropriately set in accordance with agreed contractual levels:

- Over / under
- Transiently / steady state

Frequency

The following setting levels are subjective, to the identified variations for the host Mains Grid network, and therefore set appropriately in accordance with capability considerations for the incorporated Generating Set in conjunction with agreed contractual levels:

- Over / under
- Transiently / steady state

Current

The following setting levels are subjective, to the identified operating conditions and therefore set appropriately in accordance with capability considerations for the incorporated Generating Set in conjunction with agreed contractual levels:

- Rated
- Overload
- Transient overload / Fault

Vector Shift

There is varied opinion with regard to the capability of this protection module; typically regarded as being a crude device and really only a Disturbance Detector. Therefore, it should only ever to be used as part of more sophisticated multi-parameter 'system disturbance' protection package:

- Typical setting: 10deg

Rate of Change of Frequency (RoCoF)

For the 'stiff' UK mainland Mains Grid system, the setting would be 0.3Hz/s. For a soft network such as Northern Ireland, then up to 1Hz/s.
Where the Mains Grid system is weak and there is a prevalence of renewable power generation schemes, as would be the case when the identified operational frequency bandwidth is +/-1Hz, then it may require a rate of change even higher than 1Hz/s.

Note that RoCoF modules from different manufacturers have different characteristics and so experience must be used to set appropriately.

Pole Slip

For small embedded Generating Sets, this parameter is often considered of minority interest. The initial cost of the protection module and associated Simulation Studies are often more expensive than the Generating Set.

The preferred method is still based on Impedance Tracking techniques, as this is based on alternator terminal monitoring of both voltage and current – rather than achieving an internal component connection – and therefore the MHO method is perhaps the most commonly used. Most operate by due consideration based on the equal area, along with reactive sub (and super?) synchronous reactance (impedance?) values.

Opinion suggests rotor angle should be not to exceed 90 to 110 degrees – any greater and the rotor is unlikely to retain 'polar alignment'.

Typically, the rotating diode assembly components are most vulnerable, being almost sacrificial, followed by rotor winding failures, with the damage most often occurring in the mechanical drive line components.

Surge Arresters

It is expected that overhead lines will always have appropriately installed protection to deal with imposed voltage spikes resulting from lightning strikes, or local system equipment – switching equipment. Generating Set equipment package suppliers /installers should be aware of their responsibility to consider each application and the resulting associated risk if surge protection is not present.

There are companies specialising in such packages. For example: Strike Technologies (ZORC) have a range of Surge Protection devices suitable for 400V systems and also a product specifically for Motor (read Generator) and transformer protection.

Loss of excitation

Cummins Generator Technologies have always considered the inclusion of Excitation Loss protection essential on STAMFORD and AvK alternators.

Reverse Power and Reverse kVAr

Reverse power is typically set at some 8% of nominal rating. Reverse kVAr protection should be set against levels of leading power factor, which may promote system instability.

Synchronising window

Essential parameters for frequency are:

- Frequency must match within 0.1 Hz.
- Rate of change of frequency 0.1 Hz. / second.

This *'rate of change of frequency'* is very significant, as an unstable and erratic engine speed – example; a cold gas engine – produces a circumferential rotational speed which accelerates and decelerates in a fast oscillatory manner. Such an unstable running condition may satisfy a 'Rate of change of frequency' monitor considering an average condition, and so may allow synchronisation to take place under a momentary situation where in fact the alternator's rotor is grossly miss-positioned. This will result in a compensating very high 'alignment' torque, which can damage mechanical components within the alternator or the engine to alternator drive/coupling system.

Essential parameters for voltages must match within the following parameters:

- For Generator to Mains: +/- 3%
- For Generator to Generator: +/- 0.5%

Essential parameters for Circuit Breaker closing angle follow:

The electro-mechanical stress levels generated under an unnecessarily wide closing angle can, at best, cause rotating diode surge suppressors to be damaged, or at worst, cause the stator to rotate or the shaft to twist, making the actual recommendation for the value of closing angle subjective and ultimately a matter for careful consideration by the commissioning engineer.

- If the Generating Set is to be synchronised regularly – daily – then setting to close limits will result in lowest possible stress and resulting in Generating Set longevity. Close limit is considered to be +/- 5deg.

- If the Generating Set is infrequently synchronised – put into synchronism and remains operational for many weeks before being again synchronised, the closing angle should be +/- 10deg.

- If the Generating Set has a gas engine and is, therefore; relatively unstable during the synchronising procedure, but operates continuously for long periods, the closing angle should be +/- 15deg.

Exceeding +/- 10deg should only be implemented after very careful consideration and after all attempts to set a closer angle result in failure.

G59 Certification

For connection to the Mains Grid network in the UK, the national Grid contains specific requirements for embedded Generating Sets. As the UK Grid is stable and stiff, the included setting levels are not considered suitable for weaker grids. For example; the Mains Grid system in Northern Ireland).

Conclusion

It is essential that a full technical assessment of the host Mains Grid network is undertaken prior to the installation of the proposed Generating Set equipment package. This network investigation should provide sufficient technical data to enable a Simulation Study to be conducted. From these computed results, a prediction of system behaviour will provide guidance for protection parameter settings, which should then be incorporated during installation and commissioning. The installed Generating Set protection levels settings must be tailored in line with the settings of local switchgear and any system 'deviation' monitoring protection packages that have inter-trip capability.