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A Practical Guide for EN 61000-4-28: Power Frequency Variation

Helping you solve your EMC problems

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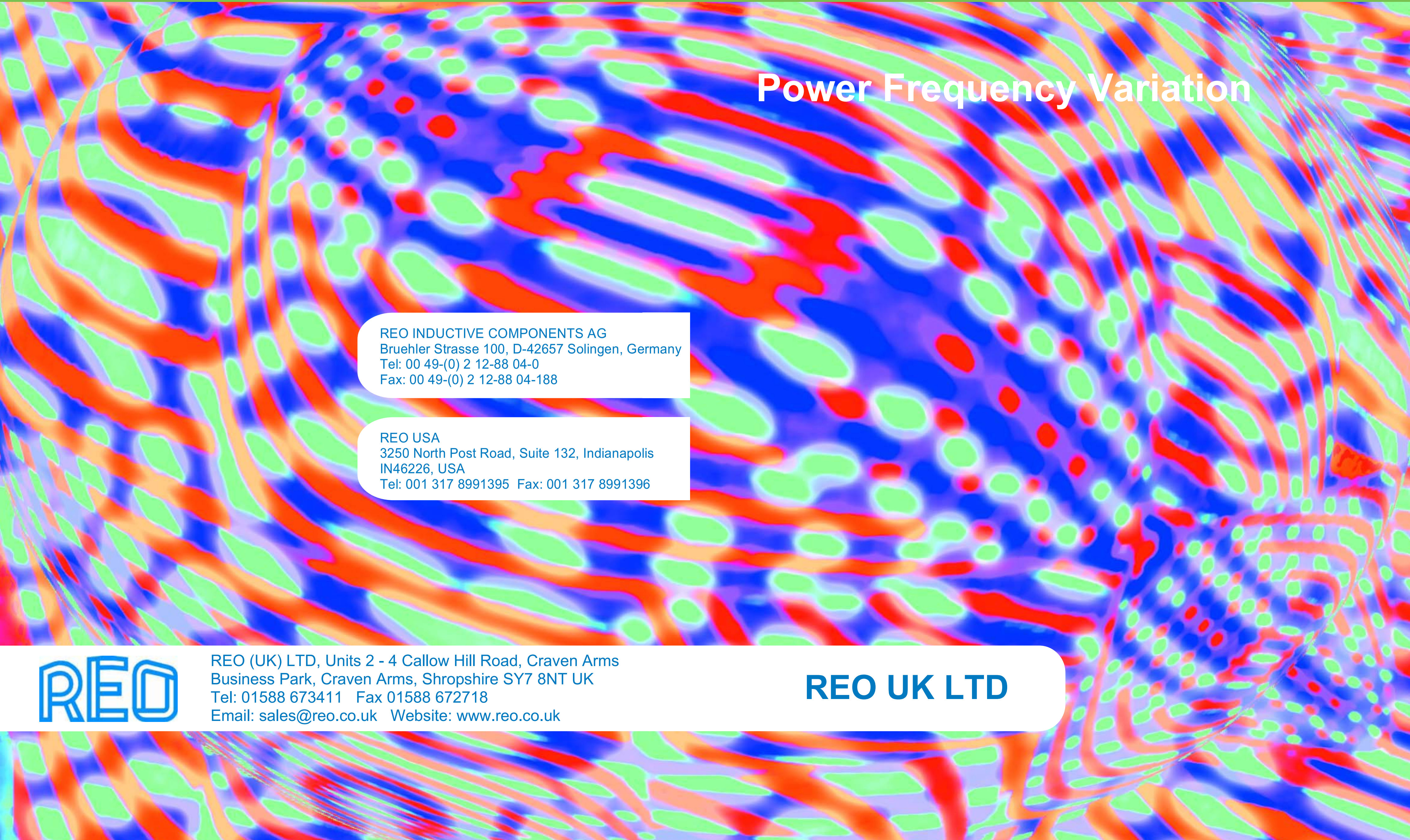
A Practical Guide on EN 61000-4-28



Power Frequency Variation

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EN 61000-4-28 and compliance with the EMC Directive

EN 61000-4-28 concerns the immunity of electrical and electronic equipment to frequency variations in their a.c. power supplies.

IEC 61000-4-28 [1] has been adopted as the harmonised European standard EN 61000-4-28 [2]. These two standards are available to be called up as basic test methods by product and generic standards listed under the Electromagnetic Compatibility (EMC) Directive, 89/336/EEC [3].

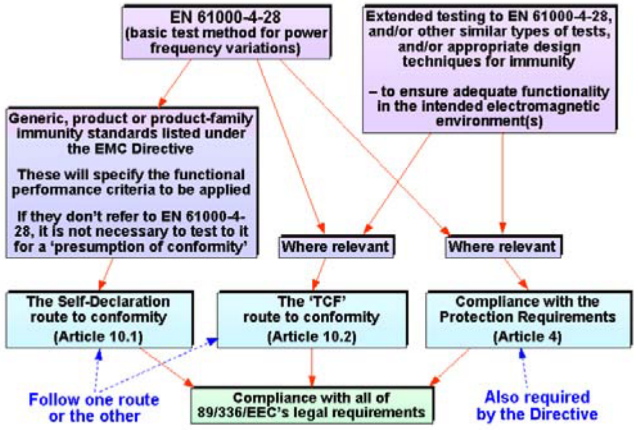
The EN version of 61000-4-28 is technically identical to the IEC document, so this booklet is of use where either standard is required. Since many national tests outside the EU, or purchasing contract requirements, are based on IEC standards, this booklet may also be of use in such situations.

The version of EN 61000-4-28 that is currently supplied by BSI (BS EN 61000-4-28:2000) includes Amendment 1 dated May 2004.

EN/IEC 61000-4-28 is what is known as a 'basic test standard', so when following the self-declaration to standards route to conformity (Article 10.1 in [3]) it need not be listed on an equipment's EMC Declaration of Conformity. Only the relevant generic or product harmonised EMC standards are *required* to be listed. Generic or product standards can call-up EN or IEC 61000-4-28 as one of the test *methods* they employ – but it is always the generic or product standard that sets the test *levels*, test *durations* and functional performance criteria that should at least be tested to allow conformity to be claimed.

At the time of writing no product or generic EMC standards listed under [3] are known to require testing to EN or IEC 61000-4-28 – but future standards (or versions of existing standards) may well do so. Plus of course this basic standard can be useful when specifying the performance of equipment for suppliers, or for manufacturers who want to improve their equipment's real-life reliability (see later).

The relationship between EN 61000-4-28 and the first edition of the EMC Directive (89/336/EEC)



When using the Technical Construction File (TCF) route to conformity with the EMC Directive (Article 10.2 in [3]) it is possible to use EN or IEC 61000-4-28 directly, in which case it *should* be listed on the equipment's EMC Declaration of Conformity. In such cases the equipment manufacturer should assess the electromagnetic (EM) environment of the equipment [4] and ensure that it is designed and/or tested accordingly, so as to comply with the EMC Directive's Protection Requirements (Article 4 of [3]).

Compliance with the EMC Directive's essential Protection Requirements applies *in addition* to the requirement to follow one of the conformity assessment routes (Self-Declaration, Article 10.1; TCF, Article 10.2; or Type Approval, Article 10.4 of [3]). Equipment that passes tests to all relevant product or generic standards that are listed under the EMC Directive, but nevertheless is unreliable or fails in normal use because it is not immune enough for the real-life EM environments in the applications it is intended for – it does not comply with the EMC Directive's essential Protection Requirements and is therefore illegally CE marked.

So, even when the Self-Declaration Route is being followed, equipment manufacturers are recommended to assess the electromagnetic (EM) environment of the equipment [4] and ensure that it is designed and/or tested to comply with the EMC Directive's Protection Requirements (Article 4 of [3]). Where an item of equipment powered from an a.c. supply could be affected by power frequency variations in its supply in normal operating environments – it may prove necessary to apply EN 61000-4-28 (or similar) in order to comply with the Protection Requirements and hence fully comply with the EMC Directive.

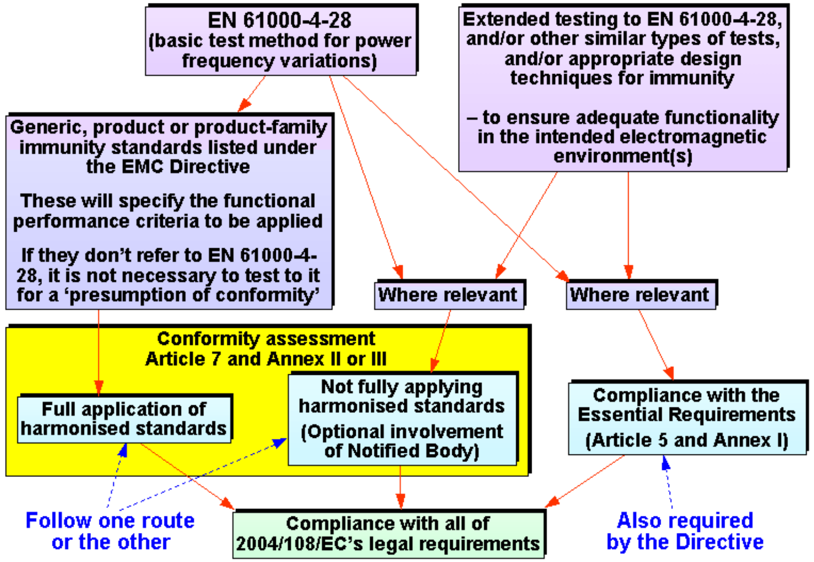
Note that because mains supply frequency variations are low-frequency events, most of their likely effects are easy to calculate using simple mathematics. So depending on the design of the equipment concerned, it may be reasonable to 'apply' EN 61000-4-28 by calculation, instead of by testing.

Applying EN 61000-4-28 or similar immunity tests which go beyond the minimum requirements of the EMC Directive's listed product and generic standards can help make equipment more reliable, reduce warranty costs, improve customer satisfaction and reduce exposure to product liability claims. This issue is addressed in the section on 'Test As Real Life', later.

The second edition of the EMC Directive, 2004/108/EC [5], replaces [3] on the 20th July 2007. Equipment already being supplied in conformity with 89/336/EEC will be allowed to be supplied until 20th July 2009, by which date it too must comply with [5] if it is to continue to be supplied in the EU. Whereas [3] requires the involvement of a Competent Body with all TCFs, [5] effectively allows the TCF route to be used with the *optional* involvement of a Notified Body (the new term for Competent Bodies).

Like 89/336/EEC, 2004/108/EC [5] also requires equipment to comply with its Protection Requirements, given in its Article 5 and Annex 1, where it sometimes calls them “Essential Requirements”. So it is recommended that all equipment manufacturers assess the electromagnetic (EM) environment of their equipment [4] and ensure that it is designed and/or tested accordingly.

The relationship between EN 61000-4-28 and the second edition of the EMC Directive (2004/108/EC)



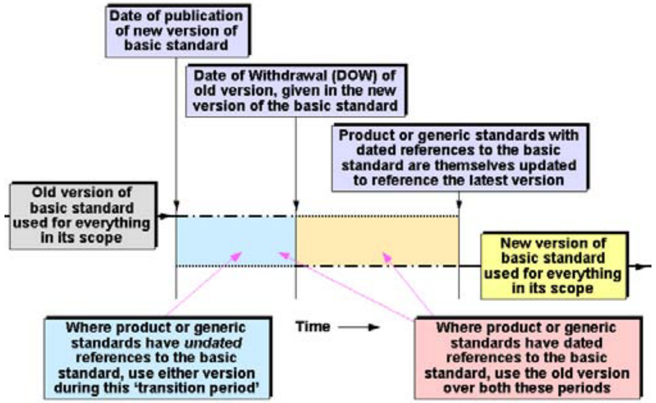
Under 2004/108/EC, all 'fixed installations' must comply with its Essential Requirements, and they must also have documentation that shows how this has been achieved using good engineering practices. Equipment manufactured specifically for use at a named 'fixed installation' may not have to comply with any EMC requirements at all – when it is supplied – but testing to EN 61000-4-28 at specified levels could be one of the EMC specifications imposed on the supplier by the purchaser, to help ensure that a particular 'fixed installation' complies with the Essential Requirements.

This booklet is part of a series that discusses a number of common EM phenomena in domestic (residential, household, etc.), commercial, light industrial and industrial environments, and how they are tested according to appropriate EN standards on emissions and immunity [6]. But other kinds of immunity tests may be required for aerospace, automotive, rail, marine, military, and other special environments. Some industries may have developed their own immunity test standards based on their own particular kinds of a.c. power supply supplies.

Important Safety Note: As a general rule, people whose health depends on the correct operation of pacemakers or other body-worn or implanted electro-medical devices should never go near any EMC immunity tests or their associated test equipment.

What to do when new versions of basic test standards are issued

What to do when new versions of the basic test standards are issued



This booklet describes how to apply EN 61000-4-28:2000. Where a generic or product EMC standard requires the use of a basic test method it will specify either a dated reference (e.g. “EN 61000-4-28:2000”), or an undated reference (e.g. “EN 61000-4-28”). If it specifies a dated reference, then this is the version of the basic test method standard that *must* be used. If it specifies an undated reference then the *latest* published version of the standard should be used. (At the time of writing, there are no versions of EN 61000-4-28 other than the 2000 one.)

But it is clearly impractical for manufacturers to rush to test labs to retest all of their types of equipment on the very day a new version is issued, so each new version of an IEC standard includes a date on which it supersedes the previous version. This is the “date of withdrawal” (DOW), and provides a transition period during which manufacturers can choose between using the old or the new versions of the standard for declaring compliance. The DOW is preserved in the EN versions of the IEC standards.

Usually it makes best commercial sense to test new equipment to the latest version of a standard, retesting older equipment when they are due for retesting anyway as a result of a design change or upgrade (as long as this happens before the DOW). Some equipment is sold for such short periods of time that they may never need to be retested to any new versions of standards.

A note of caution: the European Commission (EC) has ruled that where Directive compliance is concerned, only dates that are published in the Official Journal of the EU (OJEU) have any relevance, and not any dates put into standards by their committees. This is not a problem in most cases, but basic EMC test standards such as EN 61000-4-28 are never listed in the OJEU. Since DOW dates in the basic standards are not recognised by the EU, there can be no transition period – which is clearly impractical and silly – but this consequence does not seem to have been foreseen by the EC. It is probably less risky to always use the latest version of a basic test standard, except where the regulatory requirements (for the EU or other markets) specify the exact version to be used.

What kind of equipment is covered?

Clause 1 of EN 61000-4-28 says that it applies to: “electrical and/or electronic equipment connected to 50Hz or 60Hz distributed network with rated line current of up to 16A per phase”. Notice that it does not specify whether the power supply networks are public or private – just that they are distributed – which implies a network with more than one generator, and multiple loads, with the generators and loads spread over a large geographical area.

But since its Clause 5 sets test levels for “non-interconnected networks” it seems that its scope is actually wider than stated above, and includes equipment connected to locally generated 50 or 60Hz a.c. power supplies, down to the level of a single a.c. generator supplying a single load.

What are power frequency variations, and how do they arise?

This topic is covered by clause 3 of EN 61000-4-28. There are three basic kinds of a.c. power supply:

a) Extensive public mains distribution networks, where many generators are linked together with very large numbers of loads.
b) Local generation using rotating alternators.
c) Synthesised waveform generation such as the inverters that are used in UPSs, and also used in many types of 'green power' supplies (e.g. solar or wind power).

Extensive public mains distribution networks, where many generators are linked together with very large numbers of loads

The frequency of an a.c. power distribution is directly related to the rotational speed of the generators (alternators) that power it. As the load on the network increases, the speed of the generators decreases until the network control equipment increases the power to the generators (e.g. from burning coal, oil, gas, or oil at a higher rate; increasing the rate of nuclear reactions; letting more dam water flow through the turbines, etc.) and restores the nominal network frequency once more. As the load on the network decreases, the speed of the generators increases until the network control equipment decreases the power to them and restores the frequency.

On a large network, the effects of individual loads are usually quite small (unless they are huge loads, such as a steel-making arc furnace), but when a lot of loads are applied at once (e.g. when people make a cup of tea at the end of a popular TV programme) the effect on the network's frequency can be significant, maybe as much as three percent. Since a great many clocks use the mains frequency as their timing reference, the power supply network operators try to ensure that over any 24-hour period the periods of low frequency are balanced out by the periods of high frequency, so that on average such clocks read the correct time.

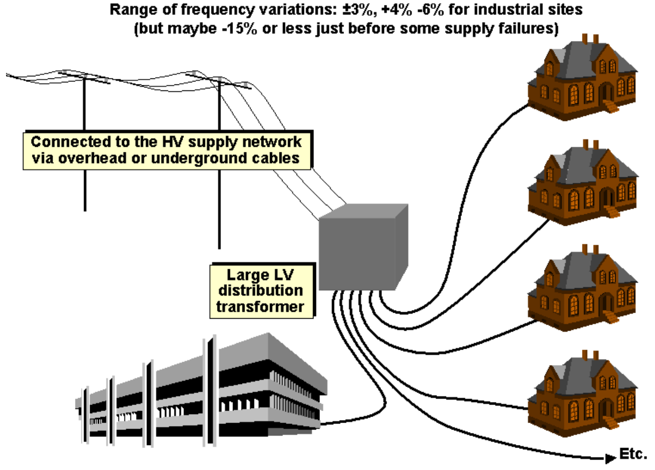
However, when there are network faults, such as a storm causing an overhead high-voltage (HV) power line to fail, the large and highly interconnected mains networks that are typical of developed countries can be split up into smaller 'islands', with a smaller availability of generator rotational inertia and power. A given load change (such as switching a large machine on or off) could now have a greater effect on the mains power frequency.

EN 50160 [7] specifies the maximum power network frequency variations in countries forming the European Union (EU) as ±1% for 95% of a week, and +4%, -6% for a full week. 5% of a week is almost 8.5 hours, so we could expect all equipment powered from mains networks in the EU to have a frequency that is 4% high, or 6% low, for periods of up to 8.5 hours. But there are some parts of the EU, and some developing countries where the mains networks are not as good as they are over most of the EU, and these could experience larger frequency variations than specified in EN 50160.

When the load demanded exceeds the generating capacity connected to a particular network island, the frequency will continue to decrease until automatic protection equipment shuts down the supply completely. The frequency variation just before the supply is shut down is not specified in any standards, and could be more than -15%.

[7] allows there to be between 10 to 50 supply interruptions per year, each one lasting longer than 3 minutes, so there could be as many as 10 to 50 times per year when the mains frequency dips momentarily below the -6% normally allowed by this standard.

Three kinds of a.c. power supply – The public supply network
(example shown is typical of Europe)



Local generation using rotating alternators

The situation with local generation is similar to that of the small islands described above, expect that the generation can be very low power (e.g. a 1kW portable generator) and the network can be very small (e.g. a single load.)

For example, the author has a 2.2kW portable generator that he uses when his mains supply is shut down, which generally occurs for periods of up to four hours, two to four times each year, usually in the winter. This is used to supply the ignition, pumps and controller for the central heating system, a refrigerator and a freezer, a few lamps and a computer. The same generator is also used with a variety of loads when making measurements in locations where mains power is not available or too inconvenient (e.g. EMC test equipment, grass cutting equipment, outdoor task lighting, etc.). Many households (especially in rural areas fed by overhead cables) keep a small generator for similar purposes.

Hospitals, 'Internet hotels' (also known as 'server farms'), data repositories, military and security sites, and some retail stores are usually equipped with rather larger 'back-up' generators so they can continue with their vital work during a network shut-down. Portable generators are often used on construction sites, to power outside-broadcast vehicles or mobile recording studios where mains power is not conveniently available. Large portable generators may be used to power whole villages, or groups of houses, sometimes for months whilst work is being carried out on their HV connection to the public supply network.

'Motor-generator sets' (MG Sets) using electric motors were often used where it was required to isolate the supply of an area, or a single load, from the main network, usually to protect one from the other (e.g. when the network has very high levels of harmonic distortion, or when the load has high levels of harmonic currents. They are still used, but are increasingly likely to be replaced by an uninterruptible power supply (UPS).

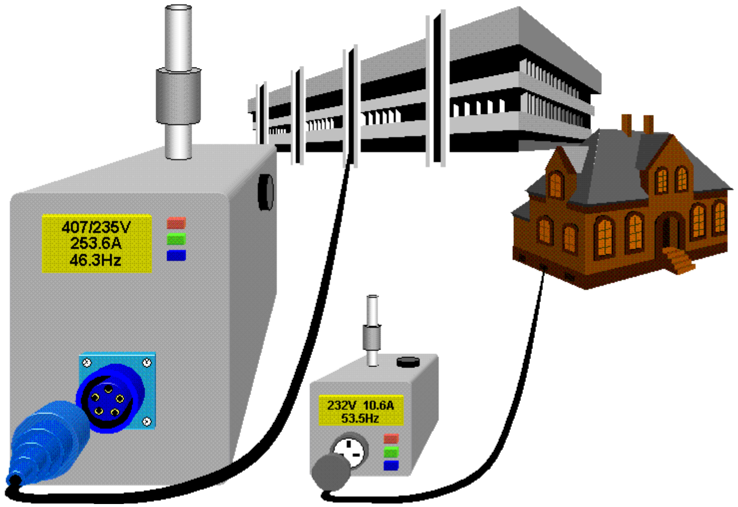
Apart from trains and trams that collect power from their tracks or overhead wires, all other vehicles and vessels must of course carry their own on-board generators. But it is usually only the larger vehicles such as large aircraft, luxury yachts or ships that have their own 50Hz or 60Hz a.c. power generators. (Smaller vehicles or vessels usually employ inverters running from the locally-generated d.c. supply, and these synthesised supplies fall into the next category to be discussed.)

The above applications use alternators driven by a motor, such as an internal combustion engine, with feedback from the mains frequency or a tachometer to control motor speed to control the generated frequency. The accuracy of the frequency control varies from one type of generator to another, and may not be very well specified. For example, the manual for the author's little 2.2kW machine has no frequency tolerance specification at all, and it changes its pitch audibly when its load changes, especially when it is overloaded, implying significant frequency changes.

These locally generated power supplies can have much larger frequency variations than is normal for the public mains distribution, and there is no control over the types of electrical or electronic equipment that can be supplied with power in this way.

Three kinds of a.c. power supply – The local generator

Range of frequency variations: up to ±15%
(but maybe more when heavily overloaded and about to trip out)

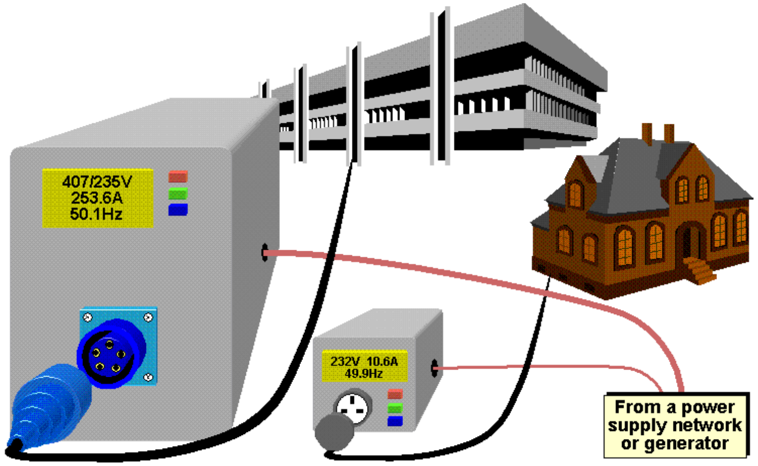


A colleague once described working on an offshore exploration oil rig in the 1980s. The rig was equipped with its own diesel generator and had a very powerful drilling motor. He told me that when the drill motor was first turned on the nominally 230V 50Hz a.c. voltage fell to almost zero, then over the next few seconds slowly ramped back up to 230V rms. When the drill motor was turned off, the supply voltage jumped to 460V rms and ramped slowly down to 230V over the next few seconds. He did not tell me what was the effect of the drill motor on the supply's frequency, but in similar situations it is not unusual to see lamp filaments pulse in brightness in time with the beat of the engine, until the speed picks up enough for the light output to be constant. So it is reasonable to assume that the frequency variation in such situations could be as much as ±90%, for a second or two.

Three kinds of a.c. power supply – The inverter
(solid-state d.c-a.c. power converter)

Range of frequency variations: maybe as much as ±2% due to initial tolerances, temperature coefficients and ageing (check manufacturer's data)

No drop in frequency even when overloaded to the point of tripping out



Synthesised waveform generation such as the inverters in uninterruptible power supplies and many types of 'green power' supplies (e.g. solar or wind power)

This category of electrical power supplies is characterised by its use of inverter technology to synthesise an a.c. power supply sine-wave by pulse-width-modulating a source of d.c. energy.

The output frequency of their a.c. power is set by their circuits, and not by the rotational speed of an alternator, and it cannot be affected by any loading placed on its output, even up to the point of trip-out due to overload.

Their frequency may only be within ±2% of 50 or 60Hz (especially for low-cost low-power inverters), due to initial tolerances, and it may vary a little due to temperature coefficients and ageing, but its frequency variations will generally be very low indeed.

This issue is covered by Clause 3 of EN 61000-4-28, which says that frequency variations can affect:

a) Control systems referring to time (measurement errors, loss of synchronisation, etc.).
b) Equipment including passive mains filters, which can become detuned.

Examples of a) include real-time clocks operating from the supply frequency, and also processes in which the rates of production are related to supply frequency. For example an induction motor driven machine may get unacceptably out of step with a DC motor, or with anything else that is controlled from a more stable time source.

Examples of b) include harmonic filters used to protect supply networks from the effects of severely non-linear loads. Such filters are carefully tuned to the 3rd, 5th, 7th (etc.) harmonics, and if the supply frequency varies significantly they may become less effective, allowing harmonic currents to flow in supply networks that are unable to deal with the resulting heating effects.

Passive harmonic filters are often 'off-tuned' slightly to help prevent the occurrence of resonances in the distribution network they are used on. If the supply frequency varies in the direction that results in peak tuning of the filters, supply resonance might occur in some circumstances, possibly resulting in severe waveform distortion, possibly leading to malfunction and damage to the equipment powered from the network.

EN 61000-4-28 mentions that a.c. motors tend to draw less power when their supply frequency reduces. But it does not mention the corollary – that a higher supply frequency causes a.c. motors to spin faster, and since the power required by most loads are proportional to some power of motor speed (e.g. the square or cube), the increased loading could be significant even for quite a small increase in supply frequency. Increased loading generally means increased current drawn from the power supply, but a.c. motors that cannot supply the power required could increase their slip speed dramatically, maybe even causing them to be unable to supply sufficient power to their loads, causing them to stall, with consequences that depend upon the application.

EN 61000-4-28 does not mention the fact that reducing the frequency of the a.c. voltage supplied to a mains transformer increases the magnetic saturation of the core and hence increases the magnetising current. This can lead to overheating transformers, and possibly even overheating in the cables that supply them. In normal circumstances this should not be a problem, but there is great pressure to keep costs low and reducing the amount of copper and iron in transformers is one way to do that. This increases the saturation of the core and the magnetising current, and makes the transformer much more susceptible to reduced frequency of operation. The range of the a.c. supply frequency should always be taken into account when designing cost-effective mains transformers.

Relays and contactors powered from the a.c. power supply (usually via an isolating transformer) and held-in at reduced voltage (to save energy) might drop out if the frequency of the supply frequency changes by a significant amount, and high ambient temperatures make this more likely. When the frequency variation returns to within a few % of nominal, they will not pull back in again because of the low value of the voltage applied to their coils.

Most electronic equipment that is powered by the a.c. mains supply simply rectifies it and converts it to d.c. to power its circuits. These are usually unaffected by small variations in the frequency of their mains power supplies, but may be badly affected by large falls in frequency.

Both linear and switch-mode a.c.-d.c. converter types will suffer increased ripple amplitude in their unregulated rails at power supply frequencies less than nominal. When the frequency falls by more than 10% or so, the effect on the equipment could be that the unregulated rail drops below its minimum value 50 or more times every second. This can have a similar effect on equipment as dips or dropouts in the supply, such as are tested by EN 61000-4-11 (see the booklet on this available from [6]). But whereas EN 61000-4-11 tests with dips or dropouts repeated three times with 10 seconds between each – high values of ripple due to low supply frequency is like each dip or dropout occurring 50 or more times per second.

Also, as described earlier, the mains-frequency transformers in linear converters can suffer increased core saturation and magnetising current at significantly reduced frequencies. The increased current might, in some circumstances, be high enough to cause fuses or other overcurrent protection devices to open.

Introduction

This booklet is not a complete recital of everything that is in EN 61000-4-28, only a general guide. Anyone performing tests to this standard should have a copy of the relevant edition, and any relevant amendments, and follow it/them exactly.

Classes of equipment

Annex B of EN 61000-4-28 specifies the three Classes of equipment according to their likely exposure to power frequency variations in their mains power supplies.

These classes only apply where products are connected directly to the Point of Common Coupling (PCC), or In-plant Point of Common coupling (IPC), with a reasonable length of mains cable that they don't share with any other products. Although the length of the cable and whether it is shared with other equipment can make important differences to voltage-related EM disturbances, such as supply voltage dips and transients, it cannot have any influence on the rotational speed of the alternators generating the voltage, so it cannot affect the power supply frequency.

Class 1

Annexes B of [1] and [2] reveal that Class 1 is for equipment that is so sensitive to mains power quality that it needs to be connected to specially protected mains power supplies, where the levels of power frequency variations are – *by the design of the installation* – significantly less than those expected on the normal mains supplies provided to domestic properties. Constant Voltage Transformers (CVTs), Motor-Generator Sets (MG sets) or certain types of UPS are typically used when creating such protected mains supplies.

The type of UPS that is suitable is the 'continuous-conversion double-conversion' type. These use the mains supply to store energy in supercapacitors, batteries or fuel cells, or some mixture of them, then use an inverter to continuously synthesise the power supply to the Class 1 equipment.

Inverters are not as reliable as an alternator, and there have been cases where a UPS that was installed to protect against power outages actually failed more often than the power supply it was supposed to be an improvement on. So, where continuity of supply is important, two UPS's each rated to supply at least the full load (or three each rated to supply at least half of the full load, to save cost), should share the load between them. Then if one unit fails and is taken off-line the other(s) will (hopefully) maintain the supply until the failed unit is put back in service. For even greater reliability, use larger numbers of UPSs in parallel so that two or more can be out of service at any one time.

Types of UPS that supply mains power and switch over to inverter mode only when certain characteristics of the mains supply go outside preset tolerances are not suitable for powering Class 1 equipment. This type of UPS costs a lot less, but usually provides very little improvement in power quality (for instance, they do nothing to control the power frequency). Usually their only purpose is to provide a.c. power when the normal supply is interrupted.

Class 1 equipment should only be supplied with a clear prior understanding between supplier and customer about the quality of the mains supply that it requires to function correctly.

Class 2

This class is for equipment intended to be connected "…*to points of common coupling (PCCs for consumer systems) and in-plant points of common coupling (IPCs) in the industrial environment in general*".

This generally applies to domestic (residential, household, etc.) and commercial networks, and also to light-industrial and industrial networks where heavy power equipment (e.g. powerful welding equipment) is not used (see Class 3 below).

Class 3

Class 3 is only for products connected to industrial mains power networks. Such networks usually have either…

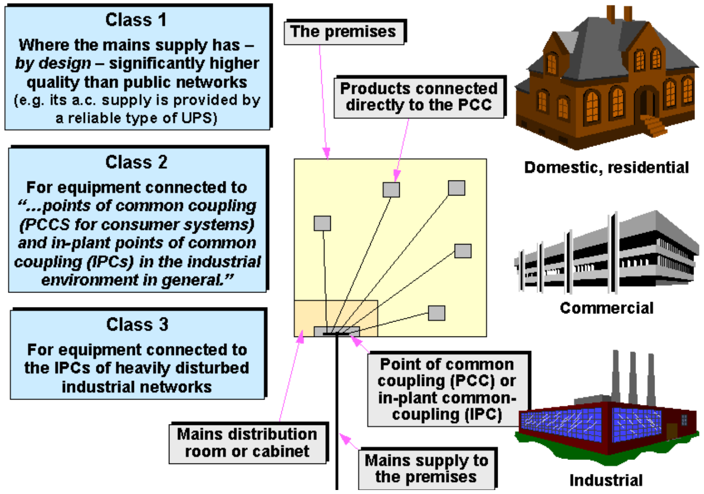
- A major part of their load fed through converters, and/or…
- Welding machines, and/or…
- Large motors or other high-power loads that are frequently started, and/or…
- Loads that vary rapidly.

The test stimuli

EN 61000-4-28 applies Test Level 1 to Class 1 equipment – but in fact Level 1 requires no tests to be applied. This is because Class 1 equipment is assumed to be protected (by the design of the installation) from power quality issues afflicting the public mains supply network.

Class 2 equipment is tested with Test Level 2: a +3% frequency variation for 120s (two minutes) repeated three times, followed by a -3% frequency variation for 120s again repeated three times. But note that ±3% variations are not as large as [7] permits for public a.c. power supply networks in the EU for up to 8.5 hours every week. Test Level 3 (below) seems to be a better specification for Class 2 equipment – more appropriate for helping complying with the EMC Directive's Protection Requirements.

The various classes of product defined by EN 61000-4-28



Class 3 equipment is tested with either Test Level 3 or 4. Level 3 is for equipment connected to an "interconnected network" (usually the public mains supply network), and Level 4 is for equipment connected to a "non-interconnected network" (usually a stand-alone generator).

Test Level 3 applies a +4% frequency variation for 120s repeated three times, followed by a -6% frequency variation for 120s again repeated three times.

Test Level 4 applies a +15% frequency variation for 120s repeated three times, followed by a -15% frequency variation for 120s again repeated three times.

Each test has a 'transition period' during which the frequency is slowly ramped up or down from/to nominal. For Levels 2 and 3 the transition periods are 10s long, but for Level 4 they are reduced to 1s. The rate of change of supply frequency can vary during a transition period, as long as it is always less than 0.5% of the nominal frequency per cycle.

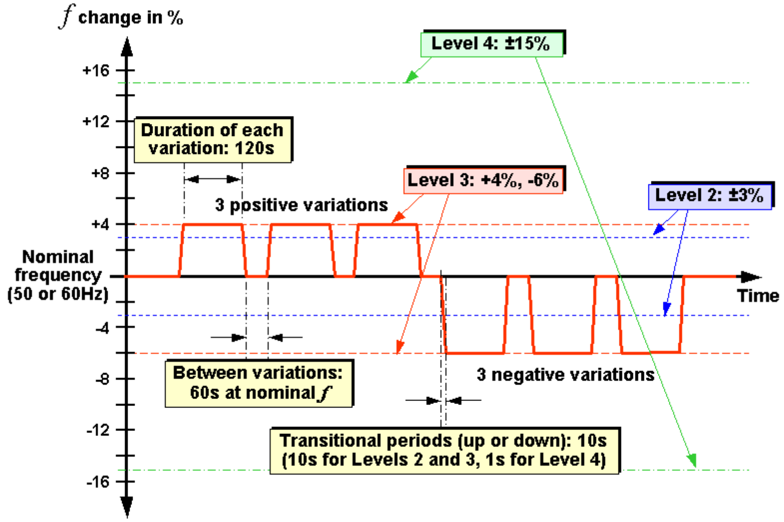
In-between each frequency variation test and its transition periods, there is a period of 60s when the frequency is held constant at nominal (i.e. 50Hz or 60Hz as appropriate).

So a full test at Levels 2 or 3 should take 1,140s (19 minutes), and a full test at Level 4 should take 1,032s (17.2 minutes) – for each of the operational modes of the equipment under test (EUT).

EN 61000-4-28 also has a Test Level X, which is called an 'open' specification. Basic test method standards cannot possibly deal with all eventualities, so the 'X' specifications can be chosen by the product or generic standard committee if they feel they are more appropriate for the type of equipment covered by their standard. The 'X' levels can also be specified by a purchaser (usually in the technical specification that forms part of their contract with their supplier), often based on a power quality survey of the particular site in question.

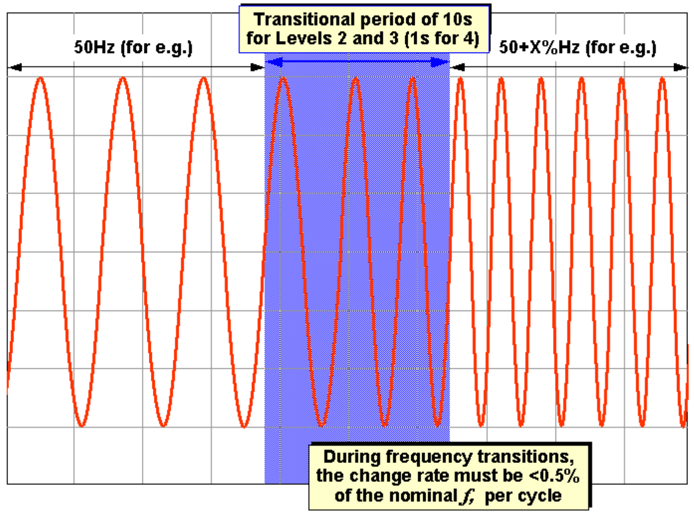
Example of a 'Level 3' power frequency variation test level sequence

(derived from Table 1 and Figure 2 of EN 61000-4-28:2000)



Example of a transitional period during a test

(derived from Figure 2 of EN 61000-4-2)
(The frequnecy has been reduced and the frequency change exaggerated for better visibility)



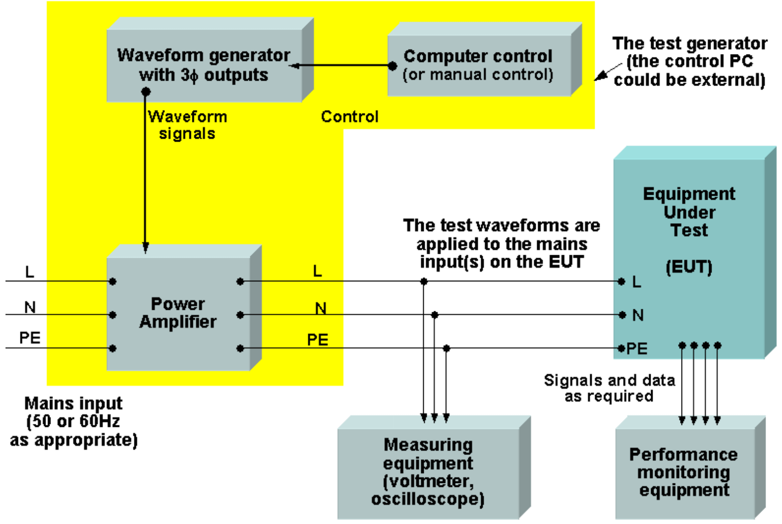
EN 61000-4-28 seems to be intended to apply to mains power distribution networks in *developed* countries (but even so is not compatible with [7], as mentioned above for Class 2 equipment). However, as already discussed, some equipment may be expected to be powered from local generation during some part of its life, and some equipment may be used in countries which have a poorer quality of mains power supply (especially developing countries). These could all suffer from power frequency variations that are worse than [7] maybe as bad (or worse) than Class 4. So, when specifying equipment that could be used on such poor quality power supplies, Class X may be very useful.

The test generator

Clause 6.1 of EN 61000-4-28 specifies the characteristics of the test generator, as follows (taken from its Table 2)….

Characteristic	Performance Specification
Output voltage accuracy:	±2% of the EUT's nominal supply voltage
Output voltage and current capability:	Sufficient to supply the EUT with its nominal voltage and enough current according to the type of EUT
Phase accuracy for each phase	2° (i.e. 0.5% of 360°)
Frequency accuracy	0.3% of the fundamental frequency (i.e. either 50 or 60Hz)
Frequency capability range	±20% of the fundamental frequency (i.e. either 50 or 60Hz)
Test duration accuracy	±10%

An example of a single phase EN 61000-4-28 test generator (based upon a waveform generator)



A three-phase test generator must have all three of its phases synchronised so that their frequencies change in the same way at the same time.

The total harmonic distortion of the generator's supply is not specified, but this booklet recommends that it should be no more than 2%.

EN 61000-4-28 says the generator must be capable of supplying "enough voltage and current according to the type of EUT". But as discussed above it is possible for some types of EUTs to draw a significantly increased current when the frequency varies, so this booklet recommends that the test generator should be able to supply this current as well.

EN 61000-4-28 says that the generator should have provisions to prevent the emissions of "heavy" disturbances that, if injected in the power supply network, might influence the test results. But this ignores the possible effect of emissions from the generator's output terminals on the correct operation of the EUT. So this booklet suggests that the test generator should meet the radiated and conducted emission requirements of the generic emissions standard EN 61326-1, with the conducted emissions being measured on it's a.c. output ports as well as on its input ports.

If you mean to buy a test generator, check that the supplier guarantees its compliance with EN 61000-4-28 and (ideally) supplies it with a calibration certificate from an independent calibration laboratory. You should then check the calibration data against the specification in Clause 6 of the latest version of EN 61000-4-28 and any amendments. Also it is a good idea to only purchase equipment that is declared by its manufacturer to comply with the EMC standard EN 61326-1 for both emissions and immunity (or similar standards), plus EN 61000-3-2 and EN 61000-3-3 (or -3-11). Better still, check the actual EMC test data to improve confidence in the truth of the manufacturer's claims.

If you want to make your own test generator you should first purchase the latest version of EN 61000-4-28 and any amendments to make sure you have the correct design data.

Verifying the test generator

Clause 6.2 of EN 61000-4-28 says that the user must verify that the test generator meets the characteristics and performance specifications as listed in its Table 2 "for the purposes of testing the particular EUT". It does not say *how* the generator's characteristics should be verified, but this booklet believes this can be done using a 'true-rms' voltmeter with additional frequency counter function, or with a oscilloscope (preferably one with the facility to measure the rms voltage and frequency). Output voltages can have the correct rms values whilst having significantly distorted waveforms due to overload or other problems, so oscilloscopes are preferred because they allow the output waveform and noise to be checked. If using a laboratory frequency counter, note that most of them will be destroyed by connecting their inputs directly to a mains supply, so their inputs will need attenuating appropriately.

Only ever use probes, leads, attenuators and test equipment that are appropriately rated and safety-approved (see the Safety Note below) and calibrated where necessary.

In place of the actual EUT, a suitably-rated resistive load that is "equal to the impedance of the EUT" may be used. EN 61000-4-28 does not say what it means by this, so this booklet assumes this statement to mean that the resistive load used to replace the EUT should equal the resistive component of the load presented by the EUT.

EN 61000-4-28 does not specify *when* the test generator's performance should be verified, but appears to imply that it should be done every time a different type of EUT is to be tested. Where an EUT has more than one operational mode, if the modes can have different power consumptions the test generator should be verified for each mode. Of course, the use of the word 'verified' means that if a generator does not meet the specification when driving the EUT, it must be repaired or replaced until one is found that does, and then the test can be carried out.

It is good test laboratory practice to verify a test generator several times in-between third-party calibrations, increasing the rate of verifications if the test generator is moved (e.g. for portable use when testing on a customer's site instead of in the laboratory). The best testing practices require the test generator's performance to be verified before each time an EUT is to be tested, or at least at the start of every day on which it is to be used.

Safety Note: When measuring voltages or currents, only use probes and equipment that have been approved by an independent safety testing body (e.g. BSI, VDE, TUV, UL, CSA, etc.) to all of the appropriate parts of EN 61010 for the appropriate 'Measurement Category' (previously known as 'Overvoltage Category' or 'Installation Category'). Measurement Category II is the *minimum* requirement, and Category III or even IV may be required for safety.

If you don't understand *exactly* what the previous paragraph means, have someone who is qualified and competent in this area sort it out for you. In some installations, special working procedures may be required. Electrical and electronic engineers are killed every year by accidental electric shocks – don't let it be you or your colleagues!

The test set-up

The test set-up is specified in Clause 7 of EN 61000-4-28, and is very simple. The output from the test generator is simply connected to the a.c. power input of the EUT via some appropriate mains cable.

Because this test does not use radio frequencies (RF) it is possible to perform it anywhere, with almost any variety of physical arrangements, and still achieve correct results. This makes it a test that is easy and low-cost for a manufacturer to perform, since it does not need shielded rooms, anechoic chambers, costly RF test gear, or test engineers who have RF skills.

The EUT should be connected in the normal manner and operated in accordance with the appropriate product or generic standard. Where no product or generic standard applies, the EUT should be tested whilst being operated in each of its modes, connected to all of its loads and auxiliary equipment as appropriate to allow it to operate as intended. The EUT should be loaded to its maximum continuous rating, where appropriate. It is permissible to simulate the auxiliary equipment required to make the EUT work correctly – if the method used will not affect the outcome of the test.

Three-phase equipment must be tested using a three-phase generator, in which all of the three phases are synchronised so that their frequencies change in the same way at the same time.

REO can create custom loads to meet any requirements

Monitoring the EUT for performance degradation during and after the tests

The functional performance degradation allowed during and after the tests may be specified by product or generic standards. Lacking these, the results should be evaluated according to Clause 9 of EN 61000-4-28 (see later).

Well before the tests are begun, the functional specifications for the EUT should be defined, and serious thought should be given to how to monitor its performance both *during* and *after* the power frequency variations tests, as required by EN 61000-4-28. The performance monitoring should achieve sufficient levels of accuracy and repeatability to be sure that the functional specifications are actually being met. This exercise helps determine in advance whether any special testing arrangements need to be organised, equipment hired, special cables and leads made up, etc., etc., well in advance of the actual testing.

It seems unlikely that a mains supply frequency variation test would upset any ancillary equipment or functional test equipment that are powered from the normal mains power supply, but since the test generators are almost always based on switch-mode power amplifiers their high frequency conducted and radiated emissions might cause some problems. Also, in some cases ancillary equipment s powered with a.c. supplied via a connector on the EUT, so it would also be subjected to the same mains supply frequency variations as the EUT.

A professional EMC test laboratory should be able to provide basic electrical test instruments that are immune enough to the influences of EMC immunity tests (check with them first). But where test instruments are provided by the manufacturer (e.g. signal or distortion analysers, display screens, computers, etc.) long periods of time are often spent trying to decide whether it is the EUT or the test equipment that is failing, all the while burning money at premium test laboratory rates.

Also, test laboratories book their time weeks (or even months) in advance, allocating customers testing timeslots that *should* be long enough to perform the required tests. Where customer-supplied functional test equipment is upset by EMC immunity tests, and no quick fixes seem to work, it is possible to run out of time trying to fix the susceptibility of the test equipment, then having to wait a few weeks (maybe months) until another time-slot can be booked to test the EUT.

Test conditions

Clause 8.1.1 of EN 61000-4-28 states that tests can be carried out under any climatic conditions, as long as there is no condensation on the EUT and the conditions are within the manufacturers' specifications for the EUT and the test equipment. Product and generic standards committees can impose climatic conditions when they call up this basic test standard, if they believe that they can affect the test results.

The EM environment in which the test is being conducted should not be so severe as to interfere with the EUT and influence the test results. EMC test laboratories should experience no problems with this requirement, but when performing the test in other locations interference might be a possibility. How to deal with interference at the testing location is discussed in a later section.

The test plan

Clause 8 requires a test plan to be prepared before starting to test an EUT. In some of the other basic test standards in the EN/IEC 61000-4 series a test plan is optional, but in this case it is a requirement. The test plan shall (at least) specify…

- The type designation of the EUT
- Information on possible connections (plugs, terminals, etc.) and their corresponding cables and accessories
- The input power port(s) that will be tested
- The representative operational modes of the EUT for the tests (remembering that each of the EUT's operational modes are to be tested)
- The performance criteria used and defined in the technical specifications
- A description of the test set-up

This booklet also recommends that the following items are added to the test plan…

- Descriptions of the ancillary equipment required to operate the EUT to simulate normal operation (for each of the EUT's operational modes)
- The descriptions of the equipment used for monitoring the EUT's performance during and after the tests, plus a description of how it is to be set-up and used
- The classification of the equipment and the test levels to be applied
- An explanation of how the uncertainties in the functional tests have been dealt with, to be able to determine whether the functional performance specification (see later) really will be achieved or not during the tests.

All power supply, signal and other functional electrical quantities should be applied within their rated ranges, and this booklet recommends that how this is to be achieved and verified should also be recorded in the test plan.

It is always a good idea to create a test plan well before the planned dates of the tests, to help identify testing and monitoring requirements whilst there still enough time to make changes, hire equipment, perform preliminary tests, etc. This helps to avoid wasting time sorting out unforeseen problems whilst paying premium test laboratory rates.

The test procedure

The test procedure is very simple: once the EUT and the (verified) test generator are set up as described above, and the equipment required to monitor the operation of the EUT is in place, the EUT is operated in each of its normal modes of operation in turn, fully loaded and connected to ancillary equipment that simulates its real-life applications. A complete sequence of tests is then applied to each a.c. power input port on the EUT, as described earlier (positive power frequency variation for 120s, three times, followed by negative frequency variation for 120s, three times).

Where there are several modes of operation, the tests are repeated for each mode, unless there is a good technical reason why this is not necessary. For example, a variable speed motor drive may need to be retested if it can be used in different speed control modes (e.g. open-loop, tacho feedback or 'vector'). If any tests are not carried out for good technical reasons, the reasons should be recorded in the test report (see later).

This booklet also recommends that the generator's output voltage and voltage waveform are monitored with an oscilloscope *during* all power frequency variations tests to ensure that it remains a low-distortion sine-wave at the required rms voltage at all times. Note that the trained human eye can usually only detect sine-wave distortion on an oscilloscope screen at levels of 2% or more.

Evaluation of the test results

Clause 9 of EN 61000-4-28 requires the EUT's functional performance during and after each test to be assessed against performance specifications defined by its manufacturer (or the person who requested the test). It recommends that the results be classified according to the following scheme…

a) Normal performance within the limits specified by the manufacturer, requestor or purchaser;
b) Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the EUT recovers its normal performance, without operator intervention;
c) Temporary loss of function or degradation of performance, the correction of which requires operator intervention;
d) Loss of function or degradation of performance that is not recoverable, owing to damage to hardware or software, or loss of data.

This classification is offered by EN 61000-4-28 as a guide to immunity standards committees if they call up this basic test method in their product or generic standards. It is very similar to the 'Performance Criteria' A, B, C (and sometimes D) already commonly used in product immunity standards, which first appeared in the generic immunity standards.

Determining a PASS or a FAIL

Being a basic test method standard, EN 61000-4-28 cannot specify how to determine whether an EUT has passed or failed its tests – but selling a equipment with a data sheet that says it achieves classification d) (see above) is potentially misleading to an uninformed purchaser, and a joke to any purchaser who is familiar with the standard. Classification d) should never be associated with a PASS result.

Equipment expected to operate automatically and unattended for several hours or longer would probably have to achieve a) or b) for a PASS. But if the equipment was always used by an operator, it might be possible to claim a PASS result when its performance on the immunity tests was c) – unless they could be so very unskilled that they could not be expected to know how to restore normal operation – in which case a) or b) would be required.

If the consequences of momentary errors or non-functionality were considered to be very undesirable, a) might be the only option. But if the consequences were acceptable, then b) or c) might be considered a PASS.

Although it is not mentioned in EN 61000-4-28, it is also recommended in this booklet that a FAIL result is recorded if the EUT becomes unsafe during any of these tests, emits any smoke or vapour, or otherwise displays any behaviour that is clearly unacceptable – even if the issue concerned is not covered in the agreed performance specification.

Test report

Clause 10 of EN 61000-4-28 describes what is required to be included in the test report, as follows:

- The items specified in the test plan (see above)
- Identification of the EUT and any associated equipment, e.g. brand name, product type, serial number
- Identification of the test equipment, e.g. brand name, product type, serial number
- Any special environmental conditions in which the test was performed, e.g. inside a shielded enclosure
- Any specific conditions necessary to enable the test to be performed
- The performance level(s) defined by the manufacturer, the requestor of the test, or the purchaser
- The performance criterion specified in the generic, product or product-family standard. (However, where this test was performed despite not being called-up by a generic, product or product-family standard – this booklet recommends that the performance criteria defined by the manufacturer, purchaser, or any other person who requested the test be detailed instead.)
- Any effects on the EUT observed *during* or *after* the application of the test disturbances, and the duration for which these effects persisted
- The rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser, or other person who requested the test)
- Any specific condition of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance

It also is a good idea to include details of the test generator verification (see above) in the report, plus a judgement on whether the test generator was functioning correctly *before* and *during* the tests, either in the EMC Test Report or in some other QA controlled document. This is so that years later, when all the personnel have changed, it can still be discovered whether a particular test had been done with a fully working generator that had sufficient voltage and current capability for the EUT.

On-site testing

Repeatability concerns

EN 61000-4-28 does not say what the generator's output impedance should be, only that it must be capable of supplying "enough voltage and current according to the type of EUT". But as discussed above it is possible for some types of EUTs to draw a significantly increased current when the frequency varies, so this booklet recommends that the test generator should be able to supply this as well. Where the test generator is sized only according to the rated supply current requirements of the EUT, it is possible for different generators to give different results, for some types of equipment.

The solution to this is to follow the earlier recommendations for monitoring the generator's output voltage and its waveform with an oscilloscope *during* the test to ensure that it remains a low-distortion sine-wave at the required rms voltage at all times *during* the tests (and recording this fact in the test report).

On-site testing to EN 61000-4-28 is as easy to do as testing in an EMC test laboratory. The only requirements are that the climatic conditions are suitable for the EUT, auxiliary equipment and test equipment; and that the EM environment is not so severe that it interferes with the EUT (making it difficult to tell whether it is the environment or the test that is causing the functional performance to go out of specification).

It is also very important to ensure that on-site tests do not cause interference, and this is the subject of the next section.

Preventing the tests from causing (or suffering) interference

Important Safety Note: Don't forget that interference, especially with aircraft or other vehicular systems; emergency services; some machinery or process control systems; life-support equipment and implanted electronic devices such as pacemakers; can have lethal consequences and appropriate precautions **must** be taken to make sure that nobody's safety is compromised by EN 61000-4-28 testing. It is also a good idea to take precautions where there is a possibility of significant financial loss being caused by interference during testing.

The programmable a.c. power supplies or power amplifiers normally used for power supply frequency variation testing use switch-mode power conversion techniques have the potential to emit significant amounts of RF noise from their a.c. mains inputs and/or a.c. output connections, that might interfere with the EUT, its ancillary equipment or the functional test equipment. Test generators commercially available from well-known EMC test equipment manufacturers would not normally be expected to cause such problems, but it is best to check that they comply with EN 61326-1 or similar.

Of course, the EUT must operate properly in the first place, and when testing on a site that suffers from high levels of EM disturbances it may be necessary to use filtering and shielding techniques to be able to distinguish the effects of the ambient noise from the effects of the test. Similarly, where the RF noise emissions (conducted or radiated) from the test generator itself might interfere with the EUT, auxiliary equipment, other test gear or any other equipment, it may be necessary to use filtering and shielding techniques to prevent this from happening.

If either of the above situations arises, there are a number of issues that will need to be taken into account to suppress the interfering frequencies effectively. Suitable filtering and shielding techniques are described in [8].

A selection of typical REO Filters for AC supplies

An example of a low-cost shielded tent
(courtesy of Hitek Electronic Materials Ltd)

It may be possible to shield the system being tested from incoming or outgoing RF with a shielded tent, and filter each of the cables entering or leaving the tent at least with a large ferrite clamp or number of small clip-on ferrite clamps, placed at the point where the cable penetrates the tent. Ferrishield, Inc. make some very large ferrites that are suitable for this purpose: their CS28B2000 has its peak impedance at 300MHz, CS25B2000 at 700MHz, and CS20B2000 at 2.45GHz. Don't forget that for a shielded tent (or other enclosure, such as mesh over a wooden framework) to be effective usually requires a shielded base that is joined to its shielded walls all around its edges. It might not be enough to simply drape a five-sided shielding tent (or mesh structure) over the EUT.

If working on exposed live equipment, an isolating transformer may be able to be used to help reduce electric shock hazards. It is best to choose special 'high isolation' types of transformers, which have a very low value of primary-to-secondary capacitance; plus choose transformers that are rated for the likely surge levels (at least 6kV, using the IEC 61000-4-5 test method) to help ensure safety.

High-isolation transformers may also be used to help prevent EMC tests from injecting noise into the mains distribution network of the rest of a site.

Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as voltages above 25V RMS a.c. or 35V peak or d.c., or with hazardous currents, energies or stored charges. If you are not sure about all of these precautions – obtain and follow the guidance of a qualified and competent electrical health and safety at work person. When constructing equipment that employs hazardous voltages, always fully apply the latest versions of all relevant parts of the EN/IEC 61010 series, at least.

Examples of REO isolating transformers

REO isolating transformer with low primary to secondary capacitances

'Test As Real Life' (TARL) for low warranty costs, other financial benefits and safety

A big problem with warranty claims and field service is the 'no-fault-found' customer return. Many manufacturers spend considerable amounts of money trying to keep their customers happy, despite not knowing what the cause of the problem is. Many no-fault-found problems appear to be caused by inadequate immunity, but interference events can be hard to repeat, and not many people know enough about EMC to even think of this possible cause, much less correctly identify such problems.

The financial rewards of producing equipment with adequate immunity can be very great indeed, as one UK manufacturer discovered when they spent £100,000 on redesigning their products to comply with the new issues of the EMC Directive's immunity standards around mid-2001, and found to their complete surprise that their new designs saved them £2.7 million in warranty costs *per year*.

But fully complying with any or all of the immunity test standards listed under the EMC Directive, or in the IEC standards catalogue, does not necessarily ensure good enough performance in real life to achieve compliance with the EMC Directive's essential Protection Requirements (see earlier) – or to achieve sufficient confidence in financial risks or safety.

So additional and/or tougher EM immunity tests may need to be applied to an equipment, based upon the real-life EM environment(s) it could be exposed to. This concept is sometimes called 'Test As Real Life' (TARL), and it is vital where high reliability is required for whatever reason. In some applications it will be necessary to base the test programme on the equipment's foreseeable EM environment(s) over its whole lifetime [4]. This is too large a subject to discuss here – refer to [9] [10] [11] [12] and [13].

If the modified or additional tests can be based on calculations based on known characteristics of the intended mains power supply network, or on measurements of the intended operational sites over a long enough period to capture the range of power frequency variations that can occur, this will help avoid both under-engineering and over-engineering.

A problem with any automatic power quality monitoring equipment is that if it is not set up correctly, it will soon fill its memory (or use up all of its paper) recording too-detailed data. If you are not skilled in these matters, and if you don't want to spend time and money going through a learning curve – instead of hiring power quality monitoring equipment from one of the many companies that provide it – hire a power quality consultant instead and have him/her do the work using their own equipment, analyse the results and produce a report.

But if the knowledge required for reasonably accurate TARL cannot be obtained, the manufacturer should decide how far to go with modified or additional power frequency variations testing, based upon their sensitivity to warranty costs and customer perceptions of their product. The author knows a large and very successful manufacturer of domestic appliances whose EMC testing goes well beyond what is required for compliance with the immunity standards listed under the EMC Directive. The reason they give for this is that their industry is highly competitive so their profit margins are very small, so they can hardly afford to have any warranty claims at all. So it is much more cost-effective for them to improve the EM design of their appliances, to reduce warranty costs, even though this adds to their manufacturing costs.

TARL and real-life power frequency variations possibilities

Safety Note: When measuring voltages or currents, only use probes and equipment that are proven to comply with the appropriate parts of EN 61010 for the appropriate 'Measurement Category' (previously known as 'Overvoltage Category' or 'Installation Category'). Measurement Category II is the *minimum* requirement, and Category III or even IV may be required for safety.

If you don't understand exactly what this means, have someone who is qualified and competent in this area sort it out for you. In some installations, special working procedures may be required. Electrical and electronic engineers are killed every year by electricity – don't let it be you or your colleagues, or anyone else!

Where real-life reliability and/or compliance with the EMC Directive's essential Protection Requirements is a concern, power supply frequency variations tests should probably be applied to equipment powered from an ordinary a.c. power supply network or rotating generator. This is despite the fact that it is not (yet) called up by any product or generic standards under the EMC Directive.

Note that because mains supply frequency variations are low-frequency events, most of their likely effects are easy to calculate using simple mathematics. So depending on the design of the equipment concerned, it may be reasonable to 'apply' power supply frequency variations by calculation, instead of by testing.

The only time that this is *not* likely to be beneficial is when the equipment is sold on the understanding that its power will only be supplied by 'continuous-double-conversion' inverter, such as certain types of UPS. But where correct operation of the equipment is important for safety, we must be aware of the fact that people do not always follow manufacturers' installation instructions to the letter, so might not connect it to the required type of supply. In this case applying the worst-case mains frequency variations is probably a good safety practice.

This section now discusses a number of situations that show why – to have sufficient confidence in reliable, accurate or safe operation in real life – it may be necessary to modify or add to the requirements in EN 61000-4-28 tests to achieve TARL ('Test As Real Life', see earlier).

Public supplies that comply with EN 50160

EN 61000-4-28 only requires Class 2 equipment to be tested with ±3% frequency variations (Test Level 2), which [7] says the normal public a.c. power supply in EU member states should supply for 95% of each week.

But [7] permits for public a.c. power supply networks in the EU to experience up to +4% or -6% for the remaining 5% of each week – a total of nearly 8.5 hours.

So Test Level 3 (+4%, -6%) seems to be a better specification for Class 2 equipment – more appropriate for TARL and also for helping ensure compliance with the EMC Directive's essential Protection Requirements. If using the EN 61000-4-28 test method, note that its test duration of 120s might not be long enough (see later).

Many types of equipment are likely to be powered by generators at some time

There is nothing to stop people from using generators that are not connected to the public supply network, and in some applications (e.g. vehicles, vessels, offshore oil or gas rigs, etc.) there is no choice but to rely on local generation.

Many types of equipment that are manufactured (including consumer appliances and electronics) can be expected to be supplied from a local generator by some users, at some point in the equipments' lifecycles – if not for their whole lives.

Equipment supplied to developing countries, or countries with poor power quality, will probably be operated from local generators, or public power supplies that provide no better frequency stability.

All such equipment should probably be tested with supply frequency variations of at least ±15% (EN 61000-4-28 Test Level 4). If using the EN 61000-4-28 test method, note that its test duration of 120s might not be long enough (see later).

Long-term effects

At some sites, significant levels of power frequency variations can be present for very long periods of time, even for years. But EN 61000-4-28 only applies its chosen tests for 120 seconds – which may not be long enough to discover any reliability or overheating effects.

For example, note that [7] permits for public a.c. power supply networks in the EU to experience up to +4% or -6% variations for a total of nearly 8.5 hours each week. There is nothing to stop this 8.5 hours being experienced in one long event, which could cause problems not discovered by a 120s test.

So, where power frequency variations can exist for longer than the tests in EN 61000-4-28, and where the EUT contains anything that could be affected by such long periods of power frequency variations, this booklet recommends testing the EUT with the anticipated long-term power frequency variations. The tests should last for as long as the power frequency variations could exist, or else for as long as it takes the EUT to reach thermal equilibrium (in the case of a physically large motor or transformer, this could be some hours).

One of the major causes of unreliability is the degradation of insulation caused by operation at prolonged high temperatures. So when conducting these power frequency variations tests, temperature sensors should be applied to the areas likely to overheat to find out whether insulation is likely to be degraded in real-life power frequency variations situations. The aim is to discover any overheating problems but stop the test before the EUT is damaged.

Especially severe environments

Environments such as the offshore oil exploration rig mentioned earlier, grossly overloaded local generators, or public power supply networks on the brink of collapse.

Simultaneous EM disturbances

All of the EN/IEC basic EMC test methods only test with one type of disturbance at a time, but in real-life an item of equipment can be exposed to two or more EM disturbances at the same time. Very little work has been done into the effects of simultaneous EM disturbances, but [14] shows that when an EUT is exposed to its full test level of one type of phenomenon (e.g. a radiated RF field of 100MHz at 3V/m) its immunity to a test that it passes perfectly well when applied on its own (e.g. fast transient bursts at 2kV) can be very severely compromised. Another transient event that might happen when an RF field (for example) is simultaneously present is an electrostatic discharge from someone's fingers.

So where a type of equipment is to be installed in areas where there is a continuous exposure to a reasonably high level of an EM phenomenon (e.g. power frequency variations in its a.c. supply) its immunity to transient disturbances – such as voltage variations, dips or dropouts – might be compromised. TARL techniques would require testing with the transient disturbances in the presence of the continuous EM phenomenon, and some analysis might help avoid a lengthy (and expensive) test programme.

It is actually quite likely that when the power supply frequency is lower than nominal due to heavy loading on its rotating generator(s) – that the supply voltage will also be lower than nominal. Similarly, when the supply frequency is higher than nominal due to light loading on its rotating generator(s) – this will usually occur at the same time as a higher than nominal supply voltage. So testing with low supply frequency and low voltage, plus high frequency and high voltage, would seem to be a reasonable thing to do for TARL.

See [6] for useful booklets describing a wide range of other EMC phenomena and their test methods.

If it is suspected that power frequency variations could be a cause of malfunctions or failures in the field, a survey with appropriate power quality measuring instruments can discover what power disturbances are occurring and whether they correlate with the failures. The instruments used are generally data-logging instruments that can be left for days (maybe weeks) unattended and automatically record details of the power frequency variations that have occurred over that period. It is rare to know in advance exactly what the cause of a problem is, so it is normal to survey a number of other power quality parameters, as well as power frequency variations, to try to correlate the likely EM disturbances with the failures that are occurring.

It helps to correlate disturbances with failures if one channel of the survey instrument can monitor something about the equipment that is suffering the problem, that indicates whether the fault has occurred or not. Then when the survey instrument's record is analysed later on, the time stamp on the event that marks the failure of the equipment can be compared with the time stamps on the disturbances that were detected, to see what EM disturbance is most likely to have caused the fault.

Where the failing equipment cannot be monitored automatically, it may be possible to have its operator, or someone else, note the date and time when it fails, for eventual correlation with the power quality survey results. If the equipment is normally unattended, it should at least be checked on a regular basis to see if it has failed or not, and the date and time noted once again. The period between checks should be no more than half of the normal time between failures, and even more frequent checking helps achieve better correlation with the measured disturbances.

A problem with any automatic power quality monitoring equipment is that if it is not set up correctly, it can soon fill its memory (or use up all of its paper) recording too-detailed data. If you are not skilled in these matters, and if you don't want to spend time and money going through a learning curve – instead of hiring power quality monitoring equipment from one of the many companies that provide it – hire a power quality consultant instead and have him/her do the work using their own equipment, analyse the results and produce a report.

Where the failure rate is low (e.g. once per month) a site survey to try to locate the cause of a problem could take a very long time. But an experienced EM engineer might already have an idea of what type of EM disturbance is the most likely cause of the failures, and after learning about the site and the other equipment installed on it might already have a good idea of what is the most likely source of that disturbance. The engineer might then be able to suggest ways of creating the EM disturbance in question (rather than wait for it to occur naturally) to see if it does indeed cause the failure. This can save a great deal of time.

Low-cost non-compliant test generators and test methods

Testing using alternative test generators and/or different types of test waveforms from those specified by EN 61000-4-28 may not be able to give 100% confidence that 'full-compliance' tests to EN 61000-4-28 would be passed. But such 'non-compliant' tests may actually be better than full testing to EN 61000-4-28 for improving the reliability or safety of a equipment – as discussed in the previous section – if the TARL (test as real-life).

EMC Directive enforcement agencies generally assume that equipment in serial manufacture are tested for continuing EMC compliance on a sampled basis, to show that no accidental changes have occurred in components, design or assembly. The costs of such a QA programme can often be considerably reduced by the use of quick, low-cost, non-compliant tests.

Because power frequency variations tests do not involve RF, it is easy to develop low-cost alternative test generators that give results useful for development and QA even though they might not fully comply with EN 61000-4-28.

Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as voltages above 25V RMS a.c. or 35V peak or d.c., or with hazardous currents, energies or stored charges. If you are not sure about all of these precautions – obtain and follow the guidance of a qualified and competent electrical health and safety at work person. When constructing equipment that employs hazardous voltages, always fully apply the latest versions of all relevant parts of the EN/IEC 61010 series, at least.

There are many possibilities for constructing test generators and creating alternative test methods, and this booklet does not seek to limit the ingenuity of electrical and electronic engineers, always assuming that health and safety is the prime concern and that it is ensured by suitably qualified and competent people.

For all but full compliance and 'pre-compliance' tests, using an uncalibrated test (for which the quantitative measurement is not traceable to the national physical standards) is not very important. But it *is* very important for *all* tests to be *repeatable* – so consistency is always required in the test generator, test methodology and test waveforms and levels. And all of the details of the test set-ups and build states should be carefully recorded in the test documentation. Photographs can be very useful, especially if annotated at the time, and digital cameras make this much easier and less costly than it used to be.

When self-declaring compliance to the EMC Directive using the 'Standards Route' to conformity (Article 10.1 of [3]) – even if alternative test generators have been used to simulate the operating environment and help achieve reliability – passing full compliance tests to EN 61000-4-28 can help avoid the possibility of legal challenges in the future.

But when following the Technical Construction File (TCF) route under 89/336/EEC (or when not fully applying harmonised standards under 2004/108/EC) it may be possible to persuade the mandatory Competent Body (or optional Notified Body) that the alternative tests and test methods represent the environment that the equipment is going into and there is no need to apply EN 61000-4-28 as well. This argument would probably be easier to win for a custom-designed (bespoke) industrial equipment intended for use at a specified site, than it would be for portable equipment or equipment that could be supplied for use in a variety of locations or sites.

Correlating alternative test methods with EN 61000-4-28

When an alternative test generator or method is used for design, development, or troubleshooting after a test failure, repeatability of the test is very important (even though the correlation with EN 61000-4-28 may not be). All such tests will need to follow a procedure that has been carefully worked out to help ensure that adequate repeatability is achieved.

When alternative methods are used as part of a QA programme, or to check variants, upgrades, or small modifications, a 'golden product' is recommended to act as a sort of 'calibration' for the test equipment and test method. Golden product techniques allow low-cost EMC test gear and faster test methods to be used with much more confidence. Refer to section 1.9 of [15] for a detailed description of how to use the golden product correlation method.

If alternative methods are used to gain sufficient confidence for declaring compliance to the EMCD, the golden product method is very strongly recommended. Without a golden product or some similar basis for correlating proper EN 61000-4-28 testing with the alternative method actually used, the alternative method might only provide any confidence at all if gross levels of overtesting are applied, and this can result in very expensive equipment.

The closer a test method is to using the same tests and methodology as EN 61000-4-28, the more likely it is that a good correlation will be achieved. Testing with a non-compliant test generator might only be able to correlated with the results from a 'proper' EN 61000-4-28 test generator for a particular build state of a specific equipment. Note that the software version is an important part of the build state – even a simple 'bug-fix' could have a significant effect on EM immunity.

Determining an 'engineering margin'

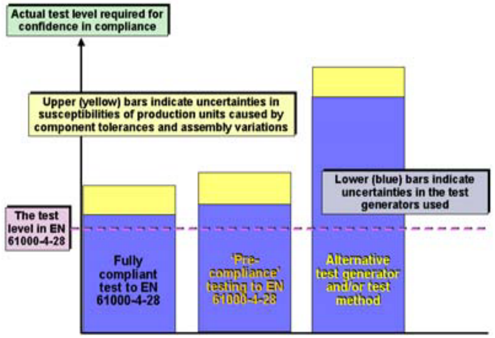
Even having EN 61000-4-28 fully applied by the same accredited EMC test laboratory cannot guarantee that a given EUT will be exposed to *exactly* the same stimuli each time it is tested. But if EMC enforcement agents test an item of equipment, they are unlikely to use the same test laboratory or model of test generator that was used by its manufacturer. So, an 'engineering margin' is recommended, because…

- There might be differences in the actual test stimuli produced by different models of generators when testing the same EUT, for example due to the rather loose specification for the generator's output capability (see earlier);
- There can be differences in the test methods, or in the assessment of the functional test during and after the EMC test, even when applied by the same staff at the same test laboratory – possibly leading to different results;
- Serially-manufactured items of equipment have a variable immunity performance due to component and assembly tolerances (e.g. the tolerance of the capacitance of the unregulated energy storage capacitor, that makes it possible for the ripple on low supply frequency to be too large for correct operation).

So, when testing an item of equipment to EN 61000-4-28 in a fully compliant manner, it is recommended that additional tests with higher test levels are also performed, with the equipment still meeting its required functional performance specifications. This will not cover the repeatability problems associated with generator impedance described earlier, but it will help take care of the second and third bullet points above.

At the time of writing it is understood that no product or generic standards listed under the EMC Directive call-up EN 61000-4-28 tests, so how (or if) a manufacturer tests for power frequency variation is entirely optional. But if EN 61000-4-28 is referenced in a product or generic standard, or if it is called up in a purchase specification, complex questions arise if alternative test methods are used instead of EN 61000-4-28 for demonstrating compliance. A larger engineering margin is recommended, at least, but how much larger can be hard to determine other than by direct comparison of the effects of both test methods on the identical equipment.

The need for engineering margins
(not to scale)



As far as doing the minimum required to achieve a presumption of conformity to the EMC Directive is concerned – saving costs and/or time by using alternative test generators or test methods can lead either to over-engineering or to non-compliance. The additional cost to make the equipment pass the alternative test method with the necessary engineering margins should be weighed against the cost of doing the testing properly.

References

[1] IEC 61000-4-28:1999, "*Electromagnetic Compatibility (EMC) – Part 4-28: Testing and measurement techniques – Variation of power frequency, immunity test*".

[2] EN 61000-4-28:2000, "*Electromagnetic Compatibility (EMC) – Part 4-28: Testing and measurement techniques – Variation of power frequency, immunity test*".

[3] European Union Directive 89/336/EEC (as amended) on Electromagnetic Compatibility. The Directive's official EU homepage includes a downloadable version of the current EMC Directive and its successor; a table of all the EN standards listed under the Directive; a guidance document on how to apply the Directive; lists of appointed EMC Competent Bodies; etc., all at: http://europa.eu.int/comm/enterprise/electr_equipment/emc/index.htm.

[4] "*Assessing an Electromagnetic Environment*", Keith Armstrong, downloadable from the '*Publications and Downloads*' page at http://www.cherryclough.com.

[5] European Union Directive 2004/108/EC on Electromagnetic Compatibility (2nd Edition), from:http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2004/l_390/l_39-020041231en00240037.pdf

[6] A number of REO booklets on other types of EM disturbances and their corresponding EN test standards can be downloaded from http://www.reo.co.uk.

[7] EN 50160 "*Voltage characteristics of electricity supplied by public distribution systems*"

[8] "*EMC for Systems and Installations – Part 4 – Filtering and Shielding*", Keith Armstrong, EMC & Compliance Journal, August 2000, pages 17-26, download it from: http://www.compliance-club.com/keith_armstrong.asp.

[9] The IEE's 2000 guide: *"EMC & Functional Safety"*, can be downloaded as a '*Core*' document plus nine '*Industry Annexes*' from http://www.iee.org/Policy/Areas/Emc/index.cfm. It is recommended that everyone downloads the Core document and at least reads its first few pages. Complying with this IEE guide could reduce exposure to liability claims.

[10] "*EMC-Related Functional Safety – An Update*", Keith Armstrong, EMC & Compliance Journal, Issue No. 44, January 2003, pp 24-30, on-line at: http://www.compliance-club.com/keith_armstrong.asp.

[11] "*Why EMC testing is Inadequate for Functional Safety*", Keith Armstrong, IEEE 2004 International EMC Symposium, Santa Clara, August 9-13 2004, ISBN 0-7803-8443-1, pp 145-149. Also: Conformity magazine, March 2005 pp 15-23, downloadable via http://www.conformity.com.

[12] "*The IEE's Training Course on EMC for Functional Safety (also for high-reliability and legal metrology)*", visit http://www.iee.org for their event calendar to check the date of the next course. If no courses are listed contact the IEE's Functional Safety Professional Network (via the same IEE homepage) and ask.

[13] *"Specifying Lifecycle Electromagnetic and Physical Environments – to Help Design and Test for EMC for Functional Safety*", Keith Armstrong, IEEE 2005 International EMC Symposium, Chicago, August 9-13 2005.

[14] *"Combined Effects of Several, Simultaneous, EMI Couplings"*, Michel Mardiguian, 2000 IEEE International Symposium on EMC, Washington DC, August 21-25 2000, ISBN 0-7803-5680-2, pp. 181-184.

[15] "*EMC Testing Part 1 Radiated Emissions*", Tim Williams and Keith Armstrong, EMC & Compliance Journal February 2001, pp 27-39. On-line at http://www.compliance-club.com/keith_armstrong.asp.

IEC standards may be purchased with a credit card from the on-line bookstore at http://www.iec.ch, and many of them can be delivered by email within the hour.

EN standards may be purchased from EU member state national standards bodies (e.g. BSI in the UK anmd AFNOR in France).

Both EN and IEC standards may be purchased from the British Standards Institution (BSI) at: orders@bsi-global.com. To enquire about a standard or other standards-based services call BSI Customer Services on +44 (0)20 8996 9001 or email them at cservices@bsi-global.com

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Keith Armstrong graduated in electrical engineering with a B.Sc (Hons.) from Imperial College London in 1972, majoring in analogue circuit design and electromagnetic field theory, with a Upper Second Class Honours (Cum Laude). Much of his life since then has involved controlling real-life interference problems in high-technology products, systems, and installations, for a variety of companies and organisations in a range of industries.

Keith has been a Chartered Electrical Engineer (UK) since 1978, a Group 1 European Engineer since 1988, and has written and presented a great many papers on EMC. He is a past chairman of the IEE's Professional Group (E2) on Electromagnetic Compatibility, is a member of the IEEE's EMC Society, and chairs the IEE's Working Group on 'EMC and Functional Safety'.

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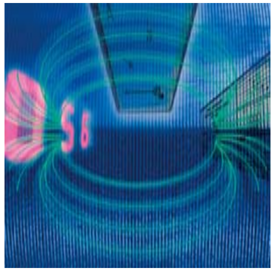
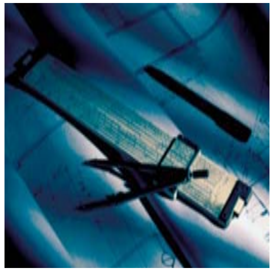


Test Systems

Power supplies and load banks

Power Electronics

Phase-angle and frequency controllers



Classics

Rheostats and variacs

Renewable Systems

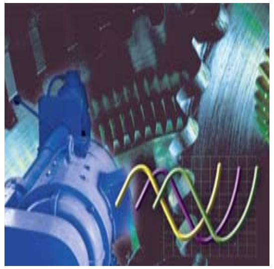
Solar transformers

Drive Systems

Filters and braking resistors

Medical Systems

Medical Transformers



Motor Control Systems

Soft-starts