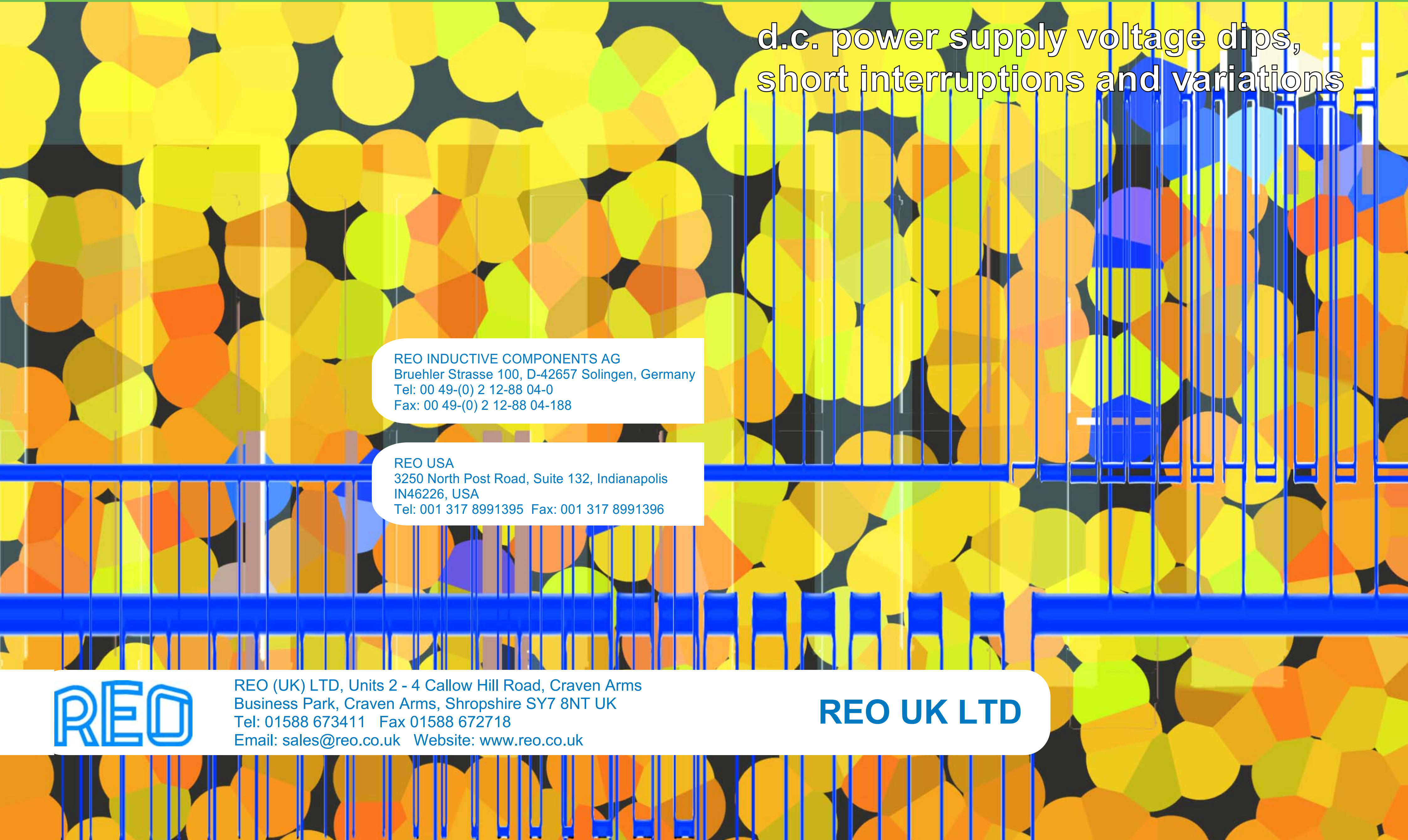
A Practical Guide for EN61000-4-29

d.c. power supply voltage dips, short interruptions and variations



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EN 61000-4-29 and compliance with the EMC Directive

EN 61000-4-29 concerns the immunity of electrical or electronic equipment, that is supplied from a low voltage d.c. power supply network, to voltage dips, short interruptions and variations in its power supply.

IEC 61000-4-29 [1] has been adopted as the harmonised European standard EN 61000-4-29 [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 61000-4-29 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.

EN/IEC 61000-4-29 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 a 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 61000-4-29 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.

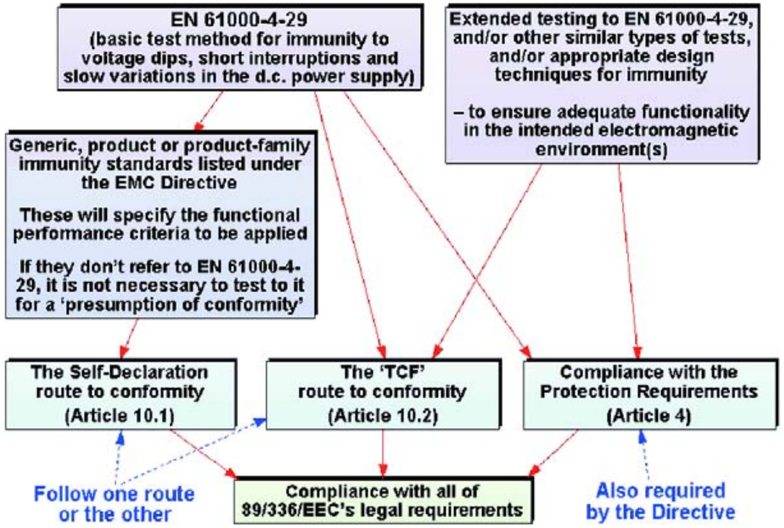
At the time of writing no product or generic EMC standards listed under [3] are known to require testing to EN 61000-4-29 but future standards (or versions of existing standards) may well do so. Plus of course this basic standard can be useful when specifying the performance of equipment for suppliers, or for manufacturers who want to improve their equipment's real-life reliability (see later).

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 61000-4-29 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 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 – does not comply with the EMC Directive's Protection Requirements and is therefore illegally CE marked.

So, where an item of equipment that is powered from a d.c. network could be affected by dips, interruptions and voltage variations in its power supply in its normal operating environments – it may prove necessary to test using EN 61000-4-29 (or similar) in order to comply with the EMCD's Protection Requirements.

The relationship between EN 61000-4-29 and the first edition of the EMC Directive (89/336/EEC)

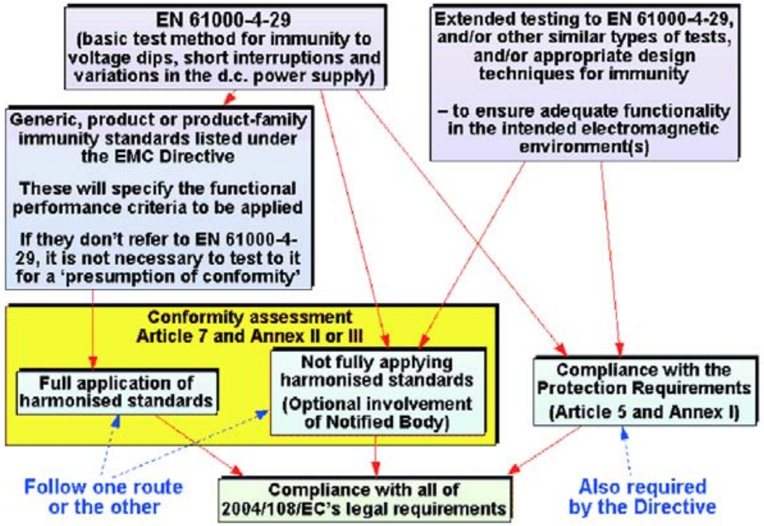


Applying EN 61000-4-29 or similar immunity tests which go beyond the minimum requirements of the EMC Directives listed product and generic standards can help make equipment more reliable, reduce warranty costs, improve customer satisfaction and reduce exposure to product liability claims. This issue is addressed in the section on 'Real-life reliability', 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 they too must comply with [5] if they are 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).

Under 2004/108/EC, all 'fixed installations' must comply with the EMC Directive's Protection Requirements and have documentation that shows how this has been achieved. 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 61000-4-29 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 EMC Protection Requirements.

The relationship between EN 61000-4-29 and the second edition of the EMC Directive (2004/108/EC)



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. 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 d.c. power supply networks. For instance: ISO 7637 tests equipment intended to be fitted in motor vehicles for their ability to withstand a number of the power quality issues associated with their 12V or 24V d.c. 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

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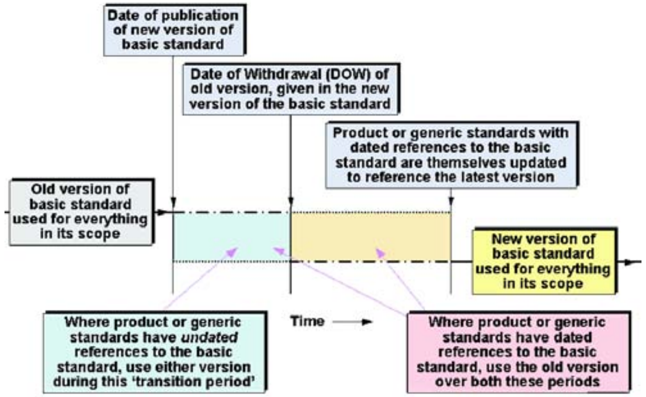
What to do when new versions of basic test standards are issued



This booklet describes how to apply EN 61000-4-29:2000. 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 61000-4-29:2000"), or an undated reference (e.g. "EN 61000-4-29"). 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 61000-4-29 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 61000-4-29 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?

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EN 61000-4-29 says that it applies to: "…low voltage d.c. power ports of equipment supplied by external d.c. networks.", and it also says that its tests apply to electrical and electronic equipment and systems. Where the rated power of an equipment or system exceeds the 25A rating of the test generator, the test is applied individually to its modules or subsystems instead.

The standard does not say what it means by "…low voltage…" but its test generator output specification goes up to 360V d.c. – sufficient to simulate the voltage provided by a rectifier operating from 254/440V a.c. mains.

EN 61000-4-29 also does not say what it means by "…an external d.c. network…", so it is assumed in this booklet that it means any d.c. supply that is shared by two or more items of electrical or electronic equipment, and that is separate to them all. For example, inside an industrial control panel it is common to find a 24V d.c. power supply that provides power to a number of small items of equipment, such as…

- Programmable logic controllers (PLCs)
- Instrumentation amplifiers
- Indicator lamps
- Human-machine interfaces (HMIs)
- Safety relays
- Relays and contactors, etc.

This booklet suggests that the above 24V d.c. supply system should be classified as an 'external d.c. network' according to EN 61000-4-29. Other examples of d.c. networks include telephone exchanges (or 'central offices') which are traditionally supplied with power at 48V d.c. so they can easily be run from batteries during a mains supply outage. The latest fashion in the computer server industry (at the time of writing) is 'blade servers'. Each blade server is effectively a single-board computer that plugs into a backplane it shares with other 'blades', with the aim of saving space, increasing data rates and reducing overall power consumption. The backplane contains data busses and (typically) 48V d.c. power from an external rectifier and voltage regulator unit. So blade servers may also be considered to be powered by an external d.c. network.

In wet environments, such as on the deck of a ship, or behind a bar where drinks are served, electrical power may be supplied by very low voltage networks (usually no more than 25V a.c. RMS or 35V peak or d.c.) to help avoid the risks of electric shocks.

Some other applications use d.c. power networks to help recover energy. Where there are large loads being moved, it is common to slow them down by using the motors that drive them as generators instead. The kinetic energy associated with the load is converted to electrical power, where it is often wasted in a braking resistor. However, where a number of motors share the same d.c. supply, or where there is a battery or supercapacitor connected to the supply, the regenerated energy can be used to accelerate another load or be stored for later use.

Refineries for sugar and uranium, and many other industrial processes, use numbers of powerful centrifuges, and some of them have been designed with a single mains rectifier unit providing a common d.c. bus network to all the centrifuges. The greatest electrical demand from a centrifuge occurs when it is spun up. By sequencing the centrifuges so that one is spun up whenever another is spun down, the rotational energy from one machine is transferred to another via the medium of the d.c. bus. Of course, there is always some loss in the regeneration process, but the end result is a much smaller and less costly rectifier unit than would otherwise be needed, and a vast reduction in the cost of electricity consumed (and in the amount of carbon dioxide indirectly emitted to warm up the planet).

Some multi-axis robotic machines, such as machining centres, are understood to use the same principle to reduce their overall power consumption. The addition of batteries or supercapacitors to the d.c. network can avoid the need to sequence the motors so one is always accelerating when another is decelerating.

Vehicles often use d.c. power networks…

- 12V in automobiles (with some 42V systems starting to be used)
- 24V in trucks
- 28V in fixed and rotating wing aircraft
- Trains and trams of the types supplied with d.c. power

Hybrid and electric vehicles often use d.c. buses of 200V or more for their traction motors, but no doubt these buses will increasingly be used for other purposes than traction.

Interestingly, EN 61000-4-29 does not limit itself to any particular kind of equipment, so presumably it is intended to be able to be applied to vehicles as well as to fixed equipment such as the industrial examples given earlier.

According to EN 61000-4-29, dips and short interruptions are sudden reductions in the d.c. supply voltage, followed after a period of time by a sudden recovery, and both are caused by random faults in the d.c. distribution system or by sudden large changes in load.

Short interruptions can also be caused by break-before-make switching between one d.c. source and another (for example between a d.c. generator and a battery), and in most networks this usually occurs much more often than short interruptions caused by faults.

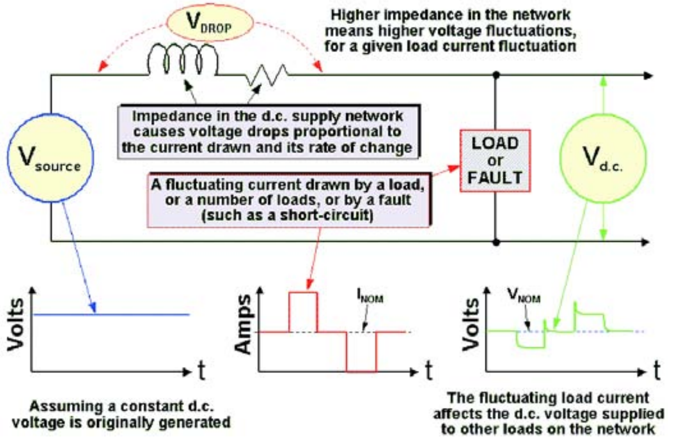
Dips are voltage reductions of up to 80%, and their durations can last from milliseconds to seconds, although EN 61000-4-29 only tests with dips lasting between 10ms and 1s.

Short interruptions are voltage reductions of more than 80%, followed after a period of time by a sudden recovery. Short interruptions are said to last up to one minute (presumably, after that they are known as long interruptions) but EN 61000-4-29 tests with durations between 1ms and 1s.

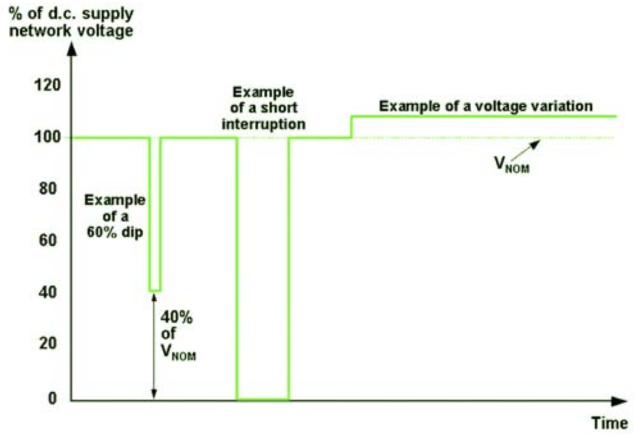
Short interruptions caused by short-circuit faults generally have a low impedance, and during this period an item powered from the d.c. network might discharge back into the d.c. network – known as a 'negative inrush current'. But short interruptions caused by open-circuit faults (such as a poor electrical connection) or by break-before-make switching generally have a high impedance.

A voltage variation is a change of the supply voltage to a higher or lower value than the rated voltage, generally caused by changes in the loading on the network and/or the charging and discharging of batteries. EN 61000-4-29 does not say how long such changes can last for – clearly they can last for many hours, maybe even days or weeks – but EN 61000-4-29 tests with voltage variations that last between 0.1 and 10s.

How d.c voltage dips, interruptions and variations can be caused by low-impedance faults and changes in load currents



Examples of d.c. voltage dips, short interuptions and variations
(not drawn to scale)



The problems that can be caused by d.c. voltage dips, short interruptions and variations

Circuits can misoperate in a number of ways when powered by a voltage that is less than they were designed for, or when that voltage is changing. How they misoperate depends on the type of circuit and on the details of how it was designed.

Analogue signal processing circuits may simply find that their maximum signal amplitude is reduced, but it is not unusual for bias levels to shift the operating points of semiconductors in such a way that they do not behave as intended – the result can be any amount of error and any type or degree of malfunction. For example, audio power amplifiers might become unstable and 'whistle' at full power at high or ultrasonic frequencies, or they may 'thump' – either of which might destroy the speakers they are connected to.

Digital circuits might reset or reboot cleanly. If they don't reset cleanly, or at all, they might experience almost random errors ranging from a change in operational mode (e.g. from crawl speed forward with reduced torque, to full speed reverse with full torque); continuously repeating a section of code; or a 'crash' or 'lock up' where the circuit ceases to operate at all.

In competently designed digital equipment a crash will eventually lead to a reboot, whereupon the equipment might then find itself in an undesirable state, depending on its application. If a reboot leaves the equipment in 'power-up' mode – this could cause problems if what is required is that the function that was being performed before the d.c. power supply disturbance should be continued. For example, a flashing lamp that indicates a hazard should continue to flash after the disturbance, and not switch off.

But sometimes the time taken by the reboot means that whatever is being controlled should shut down in a controlled manner and then require an automatic or manual restart once the correct starting conditions have been met. For example, where a number of motor drives are controlling the processing of a web of material, their speeds must be synchronised. If any one of them gets 'out of step' it risks breaking the web, which can be very costly. So it may be necessary to bring the safely to web to a halt, and restart the process when the disturbance that caused the problem is over.

An often overlooked aspect of a crash or lock-up is that the outputs of the digital circuit can be left in any random combinations of states until the successful reboot. In the case of computerised systems running large operating systems, the reboot time can be measured in minutes. During this time the digital outputs may be sending erroneous control signals to powered actuators that could create undesirable situations. In some applications such random outputs might even cause damage to the equipment being controlled, or safety hazards to its users or third parties.

Some types of high-reliability equipment, such as life-support, cannot be allowed any deviation from full-specification operation. Such equipment is often powered from an uninterruptible power supply, and in the case of d.c. power equipment this might be a battery. But where there is a network of equipment all sharing the same 'uninterruptible' d.c. network, the disturbances addressed by EN 61000-4-29 are relevant and should be tested to check that full specification operation is maintained. (Also refer to the section on real-life reliability, later.)

Power control circuits (e.g. inverter drives, switch-mode power converters) might suffer actual damage due to cross-conduction in their power switching devices, when their controlling devices suffer interference from the disturbance in the d.c. supply. The damage might extend to exploding transistors, which can create safety hazards.

Whenever there is a dip or short interruption in a d.c. power supply, transient currents will flow into and/or out of the d.c. connection of the equipment that is being powered. The voltage and current fluctuations on the d.c. conductors will cause fluctuating electric and magnetic fields; strongest near to the conductors. These fields will couple into other conductors in circuits and especially any long leads, injecting noise currents and voltages that could disturb their operation. This is most likely to be a concern for circuits that measure small signals.

Full compliance immunity testing using EN 61000-4-29:2000

Introduction

This booklet is not a complete recital of everything that is in EN 61000-4-29, only a general guide. Anyone performing tests to this standard must have a copy of the relevant edition, and any relevant amendments, and follow it/them exactly.

The test waveforms and their levels

The test waveforms are very simple, and are described in Clause 5 of EN 61000-4-29. Dips, short variations and variations suddenly change from the nominal d.c. voltage to the specified test level – then after a specified duration they suddenly change back to the nominal. When EN 61000-4-29 specifies an 'abrupt' or 'sudden' voltage change, it means one that takes between 1 and 50µs to occur (the rise/fall time specification for its test generator). Each of the tests specified in the standard is applied three times, with a break of at least 10s between each test, during which the nominal d.c. supply voltage is applied.

Voltage variations can be tested with gradual changes from nominal to the test level and back again, if required by the customer. This more closely replicates what happens in real life as a battery discharges and charges (or vice-versa).

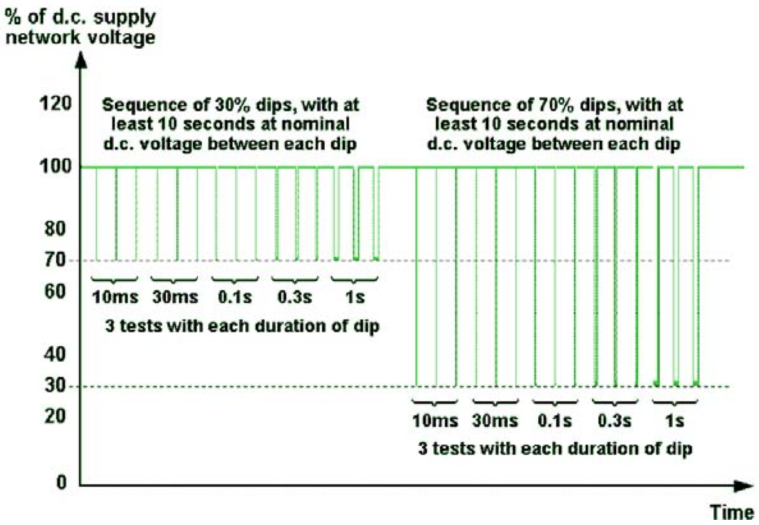
The test levels for voltage dips are:

- 30% (representing a dip of 70%)
- 70% (representing a dip of 30%)
- X (an open level which can be specified where special conditions obtain)

In all cases the dips are applied for durations of 10ms, 30ms, 0.1s, 0.3s and 1s. There is also an open duration, marked as X, which can be specified where special conditions obtain. The 'Equipment Under Test' (EUT) is tested

Example of a sequence of dips tests

(not drawn to scale)



with each level and duration of dip three times, with 10 seconds between each dip. Ignoring the X values, a full test should take about six minutes when the test sequence is under automatic control.

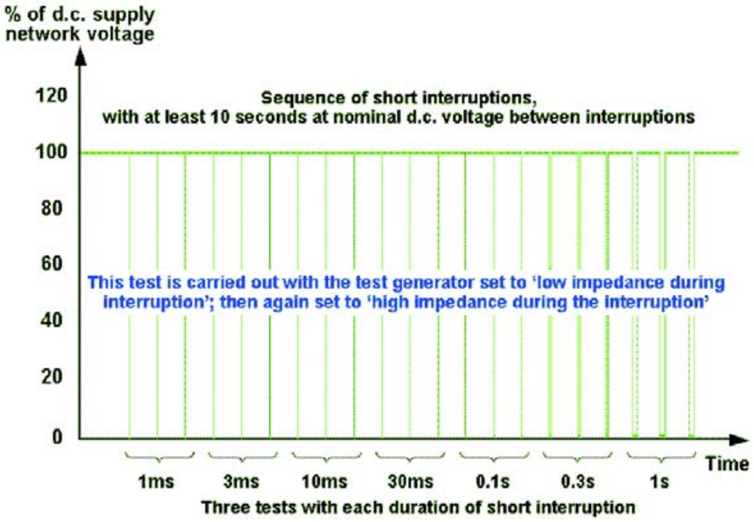
The test levels for short voltage interruptions are always 0% (representing a dip of 100%, removal of the source voltage). The durations for which the interruptions are applied are: 1, 3, 10 and 30ms, and 0.1, 0.3 and 1s. There is also an open duration, marked as X, which can be specified where special conditions obtain.

But these seven interruption tests must be carried out twice: once with a source which has a low impedance during the interruption, and then again with a source that has a high impedance during the interruption – making 14 tests in all (ignoring the X values). The EUT is tested with each duration and impedance of short interruption three times, with 10 seconds between each interruption. Ignoring the X values, a full test should take about seven minutes when the test sequence is under automatic control.

A footnote in EN 61000-4-29 says that if an equipment has been tested with an interruption of a certain duration, it is not necessary to test for any levels of dips with the same duration – "…unless the immunity of the equipment is detrimentally affected by voltage dips of less than 70%.". This would usefully reduce the number of tests, but it requires a detailed and comprehensive understanding of the behaviour of the circuits involved, when operated on voltages other than those they are intended for – knowledge that many designers do not have.

Example of a sequence of interruptions tests

(not drawn to scale)



In particular, the behaviour of microprocessor reset circuits can be compromised by dips of a certain duration although they might perform perfectly well with an interruption of the same duration. Some microprocessor and microcontroller families include reset functions within themselves, so the circuit designer could not understand them in the requisite detail in any case. So this booklet recommends disregarding this footnote and *always* doing *all* of the dips and interruptions tests.

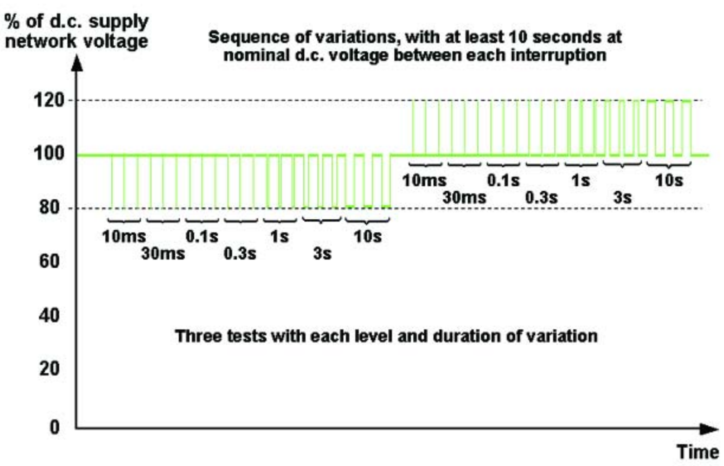
The EN 61000-4-29 tests for voltage variations are very similar to the dips tests, but with lower percentage changes in the d.c. level. They employ voltage variations that increase above the nominal as well as decrease below it (an increased voltage is caused by a reduction in the load on the d.c. network). The test levels for voltage variations are…

- 85% and 120% (representing voltage changes of -15% and +20%), or…
- 80% and 120% (representing voltage changes of ±20%), or…
- X (an open level which can be specified where special conditions obtain)

In all cases the variations are applied for durations of 10ms, 30ms, 0.1s, 0.3s, 1s, 3s and 10s. There is also an open duration 'X' which can be specified where special conditions obtain.

The EUT is tested with each level and duration of voltage variation three times, with 10 seconds between each dip. Ignoring the X values, a full test should take under three minutes when the test sequence is under automatic control.

Example of a sequence of voltage variations tests
(not drawn to scale)



Because this is a basic test standard, the above tests represent a list from which the product or generic test standard committees can choose a selection of test levels and durations. But the almost infinite variety of possible circuits in equipment, and how they might respond to dips and short interruptions, means that it is very difficult to choose. So it seems that product or generic committees usually choose which to apply based on political compromises between those who represent manufacturers and those who represent test laboratories or academia.

Since an automated test sequence that includes all of the above test levels and their durations should only take about 16 minutes (for each of the EUT's operational modes), and because we almost never know enough about the behaviour of our circuits outside of their normal operating voltages, this booklet recommends that *all* of the levels and *all* of the durations are tested for *all* of the three types of tests.

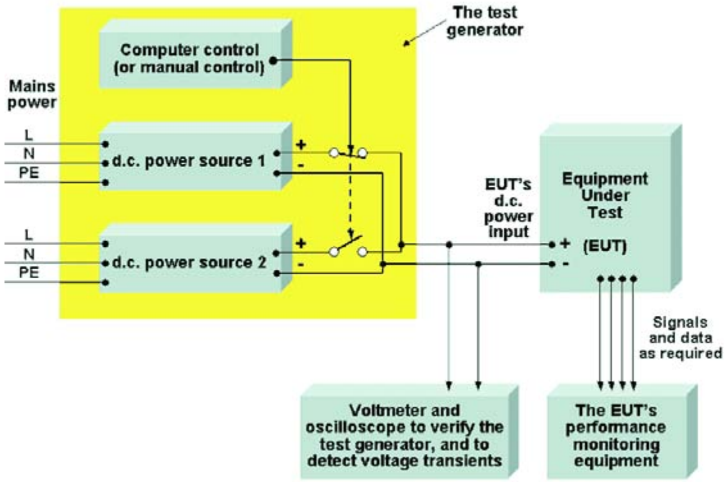
Nothing in the standard says how to choose between the 85% and 80% test levels for the voltage variations, and in fact the 85% test level is not mentioned elsewhere in the standard, even where it discusses the 80% test level. So this booklet recommends applying the 80% and 120% test levels and ignoring the 85% one.

The 'X' test levels or durations are most usually used in special applications, where the disturbances in the d.c. supply network can exceed those listed in EN 61000-4-29. The X values should be based on calculation or knowledge of the specific electromagnetic environment concerned.

The test generator

Clause 6 of EN 61000-4-29 specifies the characteristics of the test signal generator, and these specifications will not be repeated here. If you want to buy a test generator, check that the supplier guarantees its compliance with EN 61000-4-29 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 EN 610000-4-29, which means buying a copy of it. If you want to make your own test generator (which is not a difficult task) you should first purchase EN 61000-4-29 to make sure you have the correct design data.

An example of a test generator
based upon two d.c power sources with internal switching

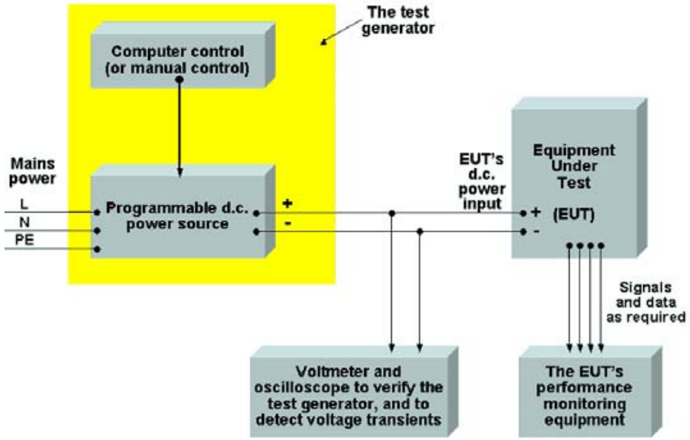


The test generator's output should be able to provide up to 360V at up to 25A. It may not always be necessary to be able to supply the maximum values of these voltages or currents – but in all cases the test generators power and current capability should exceed the requirements of the EUT by at least 20%.

The test generator specifications include requirements for when it is sourcing or sinking 'peak inrush current' during short interruptions in 'low impedance' mode. Peak inrush current is sourced when it is supplied to the EUT by the test generator, and it is sunk when it is supplied to the test generator by the EUT during a short interruption test (i.e. it flows out of the EUT back into the d.c. network during the low impedance supply interruption, sometimes called 'negative inrush current').

A peak inrush current of 50A at an output of 24V d.c., 100A at 48V and 220A at 110V should be able to be sourced or sunk by the test generator. EN 61000-4-29 does not specify what current ratings should be used for output voltages between these fixed points, but this booklet assumes that linear interpolation is intended. Higher output voltages than 110V are permitted a lower rating for sourcing or sinking inrush current, but how much less is not specified.

An example of a test generator based upon a programmable d.c. power supply



Another omission from the standard is the duration for which the peak inrush current specification should be maintained. This booklet recommends that it should be able to be maintained for at least 30% longer than the EUT requires, whether it is sinking or sourcing current.

When a lower-powered generator is used, it must be able to source or sink a 30% higher current than is demanded by the EUT – or sourced by it when the d.c. supply is suddenly reduced to zero. This appears to be the criterion that should be used when determining the peak inrush current (sourced or sunk) requirements for output voltages above 110V d.c.

The detailed requirements for inrush current take up quite a large proportion of the test generator specification in EN 61000-4-29 – in Clauses 6.1.1 and 6.2.3, and Annex B. Annex B describes how the peak inrush current should be measured, whether it is sourced (supplied to the EUT by the test generator), or sunk (supplied to the test generator by the EUT, during a short interruption test).

A surprising omission from the test generator's 'low impedance' specification is its actual impedance during dips or short interruptions. It should be "…predominantly resistive…" and low even during the switching of the output voltage, but no other specifications are given. This could lead to variations in EUT immunity performance when tested with different generators that are all 'compliant with EN 61000-4-29', or immunity problems in real life, and these issues are discussed later.

EN 61000-4-29 provides test generator specifications for when it is testing for short interruptions in high impedance mode – during the interruption the d.c. source impedance should be more than 100kΩ for voltages up to three times the nominal d.c. supply voltage. High impedance interruptions tests could cause 'flyback' voltages to be generated by the EUT, so the test generator should be protected from being damaged by them. Where the interruption is provided by an electro-mechanical relay or contactor, its ratings are adequate for interrupting the maximum d.c. currents at voltages of at least 5 (preferably 10 or more) times the nominal d.c. voltage. Such high d.c. ratings are not typical of many relays or contactors.

Most transient or surge overvoltage protectors operate in shunt mode, creating a very low impedance when they operate. So – when not relying on electro-mechanical contacts to generate the interruption – it may be quite a challenge to provide overvoltage protection that maintains the required >100kΩ output impedance during the interruption (for up to three times the nominal d.c. voltage).

EN 61000-4-29 does not specify the amount of noise, or its spectrum, permitted on the test generator's power inputs or outputs. This booklet recommends that they should have low enough levels of noise on their power inputs that they will not interfere with any other equipment powered from the same a.c. supply network. They should also have low levels of noise on the d.c. power outputs so that they are unlikely to interfere with any type of EUT and confuse the results of the test.

Verifying the test signal generator

Clause 6.2 of EN 61000-4-29 describes how the generator's characteristics are to be verified. This is simply done using calibrated voltmeters, ammeters (or current shunts and voltmeters) and storage oscilloscopes (e.g. a typical 'digital' oscilloscope) to measure output voltages, switching times, inrush currents, and output impedance when in high impedance mode.

The voltages are measured with no load on the generator, and then again with the EUT connected to check that they remain within 5% of their correct values.

These verification tests require the use of standard electrical test instruments and electrical test methods, so are not described here. If you are going to do any testing to EN 61000-4-29 you should buy a copy of it and follow its verification requirements.

Inrush currents are measured onto a specified test load (a 1700μF capacitor). Verification techniques for use when lower generator ratings are used are also specified, to check that the generator is 20% more powerful than the EUT requires (30% in the case of peak inrush currents).

EN 61000-4-29 does not say how often the generator's performance should be verified, but the implication of the requirement to check that the voltage levels remain within 5% of specification when driving the EUT is that the test voltages, at least, are verified for each EUT tested. Where an EUT has more than one operational mode, the test voltages should all be verified for each of them in turn when they are tested.

It is good test lab 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 customers site instead of in the laboratory). The best testing practices require the test generators performance to be verified before each time an EUT is to be tested. It may be reasonable to devise a verification test that is very quick and easy to do, or to only verify a number of its key parameters, as a check that the generator has not been damaged since it was last fully verified or calibrated.

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 and Annex A of EN 61000-4-29, and is very simple. Basically, the d.c. power output from the test generator is connected to the d.c power input of the EUT using a very short power cable. Where the EUT manufacturer specifies the shortest power cable length, then this is the length that should be used. Otherwise, the cable length should be the "…shortest possible length suitable for the EUT's intended application.".

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 it 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 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.

REO can create custom loads to meet any requirements

Monitoring the EUT for performance degradation during 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 61000-4-29 (see later).

Well before the tests are begun, the functional specifications for the equipment should be defined, and serious thought should be given to how to monitor the EUT's performance both during and after the tests. The performance monitoring should achieve sufficient levels of accuracy and repeatability to be sure whether its functional specifications are actually being met. This helps determine in advance whether any special testing arrangements need to be organised, equipment hired, special cables and leads made up, etc., etc.

Clause 8 of EN 61000-4-29 requires that monitoring equipment is provided to measure the status of the operational mode during and after each test, and to measure the functional performance after each test. But complying strictly with this requirement would not allow the functional performance to be monitored during a test – making it impossible to make a pass/fail judgement for performance classification a) in clause 9 (see later). It would also make it difficult to comply with the requirements for the test report listed as the eighth bullet point in Clause 10 (see later).

So this booklet recommends instead that where it is a requirement that the functional performance is not degraded by too much during a test – then the EUT's monitoring equipment should measure both the status of its operational mode, *and* its functional performance, with sufficient accuracy both during and after each test.

An accredited test laboratory should be able to provide basic electrical test gear (check with them first) that is immune enough to the influences of EMC immunity tests. 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 timeslot can be booked to test the equipment.

Test conditions, test plan and test execution

Clause 8.1.1 of EN 61000-4-29 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 they can affect the test results.

Clause 8.1.2 says that the electromagnetic (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.

Clause 8.2 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 test levels and their durations that are to be applied to the EUT
- The representative operating conditions of the EUT during the above tests (remembering that each of the EUT's operational mode are to be tested)
- The auxiliary equipment required to operate the EUT to simulate normal operation (for each of the EUTs operational modes)

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.

This booklet also recommends that the equipment used for monitoring the EUT's performance during and after the tests is also listed in the test plan, along with a description of how it is to be set-up and used – and an explanation of how the measurement uncertainties have been dealt to be able to determine whether the functional performance specification (see later) has been achieved or not.

It is always a good idea to create a test plan well beforehand, to help identify testing and monitoring requirements ahead of time. This helps to avoid wasting time sorting out unforeseen problems whilst paying premium test laboratory rates.

The output of the test generator should be monitored during each test with an accuracy better than ± 2% – which will require a storage oscilloscope to be able to measure the voltages during the dips and short interruptions, because a meter would take too long to respond. EN 61000-4-29 does not say what should be done if the test voltage goes outside the specified limits for the test generator, but this booklet assumes that the intention is to cancel the test if this occurs, and to get the test generator repaired before it is used again.

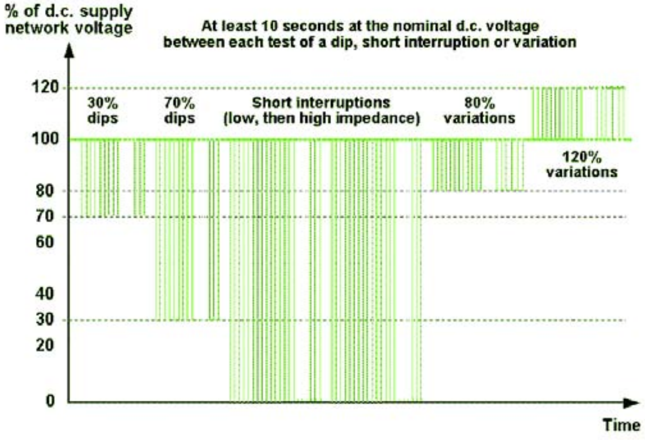
The test procedure

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, fully loaded and connected to auxiliary equipment that simulates its real-life applications, and the tests are applied as described earlier.

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 d.c. powered 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.

Voltage dips or short interruptions can cause transient overvoltages to appear at the EUT's mains input terminals, and these can sometimes be a cause of interference. EN 61000-4-29 requires such transients to be monitored and recorded in the test report, but does not require any action to be taken on them. A test generator with rise/fall times near to 1µs is much more likely to cause high levels of transient overvoltage than one which is closer to 50µs. Note that this may result in significant differences between the performance of equipment on this test when tested with different models of test generator, even when the generators are all 'fully compliant with EN 61000-4-29'.

Example of a full sequence of EN 61000-4-29 tests
(not drawn to scale)



Evaluation of the test results

Clause 9 of EN 61000-4-29 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 are 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 61000-4-29 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 61000-4-29 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. In any case, classification d) could never be associated with a PASS result.

Some of the d.c. voltage disturbances tested by EN 61000-4-29 might be expected to occur fairly frequently, depending on the application. In these cases, performance classifications a), b) or c) might be acceptable for a PASS result in the test report (see below).

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 61000-4-29, it is also suggested 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 anything that is clearly unacceptable – even if the issue concerned is not covered in the agreed performance specification.

Test report

Clause 10 of EN 61000-4-29 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 not performed because it was 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)
- Any specific condition of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance

Don't forget that Clause 8.2 requires that the test generator's output voltage is monitored during the test, so the test report should include something to show that this was done, and something on its results. And clause 8.2.1 requires any transient overvoltages appearing at the EUT's mains input to be recorded in the test report, although this doesn't appear in the list in Clause 10.

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, 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.

On-site testing to EN 61000-4-29 is as easy to do 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, some machinery or process control systems, 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 61000-4-29 testing. It is also a good idea to take precautions where there is a possibility of significant financial loss being caused by interference during on-site testing.

When not using test generators commercially available from well-known EMC test equipment manufacturers, programmable d.c. power supplies that use switch-mode power conversion techniques have the potential to emit significant amounts of RF noise from their a.c. mains inputs and/or d.c. output connections, that might interfere with the EUT or the auxiliary equipment.

Of course, the EUT must operate properly in the first place, and if 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 [6].

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 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 the 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.

REO isolating transformer with low primary to secondary capacitances

Examples of REO isolating transformers

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.. 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.

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 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 a 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 [7] [8] [9] [10] and [11].

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 unbalance that can occur, this will help avoid both under-engineering and over-engineering.

But if the knowledge required for reasonably accurate TARL cannot be obtained, the manufacturer should decide how far to go with modified or additional unbalance 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 way beyond what is required for compliance with 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 cannot afford to have any warranty claims at all, it is much more cost-effective for them to improve the EM design of their appliances, even though this adds to their manufacturing costs, to reduce warranty costs.

If it is suspected that d.c. voltage dips, interruptions and variations are a cause of failures in the field, a survey with appropriate power quality measuring instruments can discover what events are occurring and where they are being generated. These may need to be data-logging instruments that can be left for days (maybe weeks) unattended and automatically record details of the voltage changes that have occurred over that period.

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 dont 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.

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!

Comparing real-life d.c. supply network power quality issues with the EN 61000-4-29 tests

The product and generic standards listed under the EMC Directive will generally apply the following immunity tests to d.c. power supply inputs…

- Fast transient bursts (to EN 61000-4-4)
- Conducted RF 150kHz to 80MHz, amplitude modulated with 1kHz sine wave at 80% (to EN 61000-4-6)
- Radiated RF 80 to 1000MHz, amplitude modulated with 1kHz sine wave at 80% (to EN 61000-4-3)
- Surges (to EN 61000-4-5, usually only for very long d.c. cables)

There are REO booklets on all of the above types of disturbances and their EN/IEC test methods, available from [12].

EN 61000-4-29 is one example of a test that probably should be done, where an equipment is powered from a d.c. power supply network, if real-life reliability or compliance with the EMC Directive's Protection Requirements is a concern. This is despite the fact that it is not yet called up by any product or generic standards under the EMC Directive.

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 above tests to achieve TARL (Test As Real Life, see above).

Some TARL d.c. supply network power quality issues

Ripple on the d.c. network, caused by a mains rectifier

This can be tested by applying EN 61000-4-17. (But be aware that in some d.c. networks the ripple or noise may not simply be the traditional 'mains ripple' caused by charging and discharging of the storage capacitors from the mains rectifiers. See the section on harmonics and interharmonics later.)

Transient overvoltages caused by faults and other causes

As mentioned above, these can be tested by applying EN 61000-4-4 – but direct injection should be used instead of the capacitive clamp method. There is a REO booklet on this test standard at [12]. For equipment for fitting to motor vehicles the appropriate test standard is ISO 7637, with test levels at least Class II and maybe as high as Class IV [13]. (Note that motor vehicle manufacturers may well apply other tests, or higher level tests, on the d.c. inputs of equipment intended to be fitted as 'original equipment').

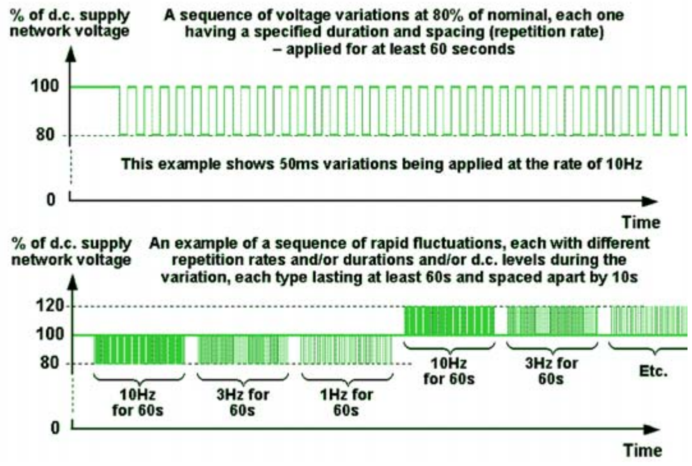
When a transient overvoltage is caused by a fault in the d.c. network, the transient occurs at the same time as the change in the d.c. supply level, so testing with transients on their own might not have the same effect – see the section on simultaneous disturbances, later.

Pulses of increasing d.c. voltage

When the load on a d.c. power network reduces, the d.c. voltage can rise either momentarily or permanently (depending on the type of d.c. source). EN 61000-4-29 tests with 120% pulses, under what it calls its “voltage variations” tests.

Clause 8.2.2 allows testing with voltage variations that are slowly varying, to simulate batteries charging or discharging (see later), but it does not say whether these tests are in addition to, or replace, the abrupt voltage variations tests described in its clause 5. Because slowly varying d.c. voltages have different causes from abruptly varying d.c. voltages, and because they can have different effects on electronic circuits and devices, this booklet recommends that where both can happen – both are tested.

An example of a possible d.c. voltage 'rapid fluctuation' test
(not drawn to scale)



Rapid fluctuations in the d.c. voltage

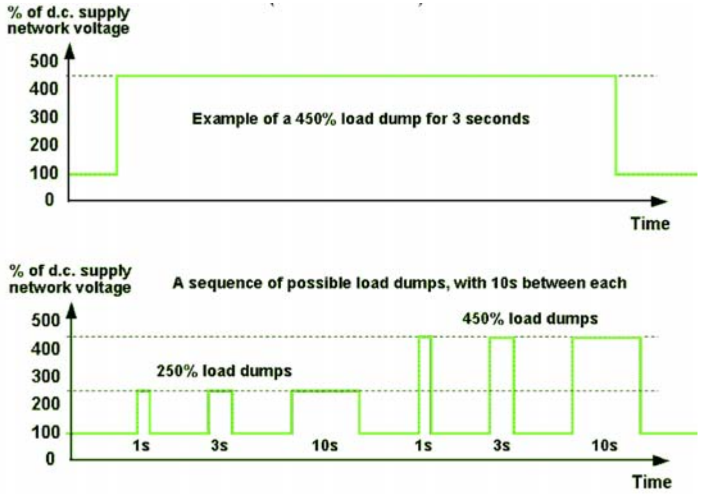
These can be caused by rapidly fluctuating loads, or by intermittent faults, and they can also be caused by rapid fluctuations in a.c. supply voltages that power the d.c. network. The fluctuations can consist of large numbers of dips or short interruptions such as are used in the EN 61000-4-29 tests, or numbers of pulses such as those discussed in the bullet point above. They might even alternate between a dip and a pulse.

Rapid a.c. voltage fluctuations are addressed by testing to EN 61000-4-14 [12], but there are no EN or IEC standards covering rapid fluctuations on d.c. networks. However, it would be very easy to modify the EN 61000-4-29 voltage variations test method to test for rapid fluctuations instead, simply by reducing the time between each variation to 1 second or less, and applying each sequence of variations for a period of at least 60s. The REO booklet on EN 61000-4-14 gives useful guidance on the rates of fluctuation to test for, in its section entitled: “*Comparing real-life mains voltage fluctuations with the EN 61000-4-14 tests*”.

'Load dump'

This is a type of voltage surge caused by open-circuit faults in the d.c. supply network when one or more of the items of equipment connected to the network is an energy source (for example: an alternator in a motor vehicle; a motor drive with regenerative braking; a battery charger; etc.). It is really a version of the increasing voltage variations test in EN 61000-4-29, except that because of the energy source connected to the network (that is now disconnected from its battery or other low impedance sources or loads) the voltages may be higher, the power levels will almost certainly be higher, and the durations could be longer.

An example of a possible 'load dump' test
(not drawn to scale)



Load dump transients can peak at up to a few times the nominal d.c. voltage (e.g. 60V for a 12V system) and can often deliver very large amounts of destructive energy (important considerations when selecting the ratings of the overvoltage protection suppression components for an equipment).

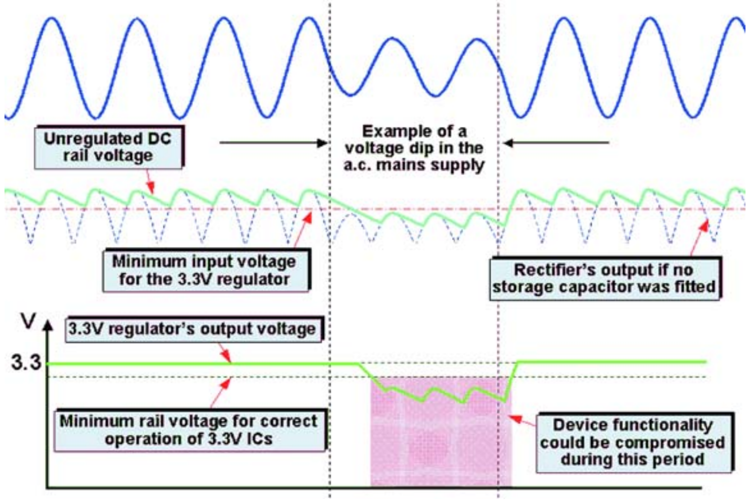
There are no IEC or EN tests for load dump, but for motor vehicles the appropriate test is included in ISO 7637 and is based on the typical characteristics of the alternators fitted to vehicles. Other types of energy sources can be very different from motor vehicle alternators, and unfortunately we have no guidance in any IEC or EN standards on the load dump disturbances they could create. If the energy sources that will be attached to a d.c. network are known, their load dump characteristics can be found by calculation, simulation or testing and the EUT tested accordingly. Otherwise, an equipment manufacturer who is concerned about reliability is faced with doing a wide range of load dump tests that may not be necessary for real-life reliability, risking over-engineering.

Dips, short interruptions and variations caused by disturbances in the a.c. supply

Where an a.c.-d.c. converter supplies power to the d.c. network, or charges its battery – dips, short interruptions and variations in the a.c. supply can cause disturbances in the d.c. supply. Such disturbances in the a.c. supply are addressed by EN 61000-4-11 (see the REO booklet on this standard [12]).

In general, these a.c. disturbances will cause corresponding disturbances in the d.c. supply voltage – but their percentage amplitudes and durations will be larger or smaller than the a.c. disturbances (depending on the design of the a.c-d.c. converter or battery charger). Where there are 'smoothing' or 'storage' capacitors fitted in the a.c-d.c. converter powering the d.c. network, the rise/fall time of the d.c. disturbances will generally have slower rise and fall times than those tested by EN 61000-4-29. Note that some six-pulse or twelve-pulse a.c.-d.c. converters running from three-phase supplies do not employ smoothing or storage capacitors (this is typical of some aircraft d.c. supplies) – so changes in their a.c. supplies will be reflected immediately in their d.c. outputs.

An example of how a.c. voltage dips, dropouts and interuptions can cause problems for d.c. powered devices (example of a 3.3V d.c. circuit)



So, *in general*, testing to EN 61000-4-29 will cover the effects of dips and short interruptions in the a.c. supply. But this general assumption should always be queried, since some a.c-d.c. converters may respond in a complex manner to some a.c. disturbances (especially if they employ microprocessor-based control).

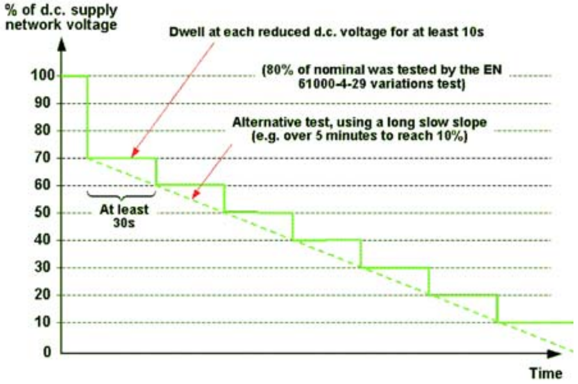
Heavily-discharged batteries

Clause 8.2.2. of EN 61000-4-29 permits product and generic standards to specify slow voltage variations that simulate the charging and discharging of batteries, where appropriate, but gives no guidance on the test levels that should be used.

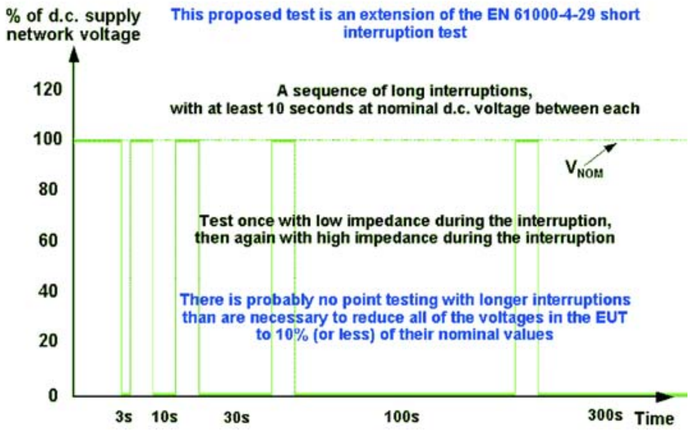
So it is recommended in this booklet that where the EUT might be powered from batteries that could be heavily discharged, maybe even until they are 'flat', they are tested using the voltage variation test method in EN 61000-4-29 but with voltage levels that are 70%, 60%, 50%, 40%, 30%, 20% and 10% of nominal, dwelling for at least 30s at each voltage level.

Where overheating or some other physical effect seems to be occurring to the EUT, or analysis shows that such effects could occur, it is recommended that the duration of the test is extended indefinitely, at the supply voltage that causes the potential problem, to see if the equipment becomes damaged as a result.

An example of a possible discharging battery test
(not drawn to scale)



An example of a possible d.c.voltage 'long interruption' test
(not drawn to scale)



Dips, interruptions and variations that are shorter, longer and/or have different levels

The dips, interruptions and variations tests in EN 61000-4-29 are a subset of an infinite variety of such tests, which can vary in voltage level, duration of the changed level, the rise/fall time of the changes and the intervals between the changes. Presumably the committee that wrote the standard chose values that are typical of a wide range of d.c. networks, although no references are given for the sources of this basic data.

But it is clear from even a cursory inspection that the d.c. voltage can dip to levels other than 40% and 70%, and the dips can last for less than 10ms, and maybe longer than 1s. It is also clear that interruptions can last much longer than 1s, for example when the a.c. power that supplies the d.c. network is interrupted for several hours, or if a protective fuse is opened or power supply 'foldback' current limit circuit is activated.

It is also clear that voltage variations can be smaller or larger than ±20%, and can last for less than 0.1s or longer than 10s. All these possibilities are covered by the 'X' categories in Clause 5 of EN 61000-4-29. Don't assume that larger voltage changes are necessarily more of a threat to an EUT – for example some circuits and devices will reboot correctly after a severe dip or interruption, but their reset circuits can be 'fooled' by smaller voltage changes.

When TARL is a requirement, the d.c. network that supplies the EUT should be analysed and/or monitored and if it turns out that the tests in EN 61000-4-29 would not prove the reliable operation of the EUT for some reason, additional dips, interruptions and variations tests should be done to create the necessary confidence.

There is usually no point in continuing an interruption for any longer than is necessary for all of the voltages inside the EUT to collapse to 10% (or less) of their nominal values.

Harmonic and interharmonic distortion of the a.c. supply waveform

These a.c. supply disturbances are addressed by EN 61000-4-13 (refer to the REO booklet on this [12]), and can affect the d.c. output level and ripple of mains rectifiers. The effects on the d.c. voltage are to cause it to vary, a type of disturbance that is addressed by the voltage variation tests in EN 61000-4-29.

But another effect of harmonics and interharmonics in the a.c. supply is that the d.c. network ripple may not simply be the traditional 'mains ripple' (caused by charging and discharging of the storage capacitors from the mains rectifiers). The ripple can contain significant amounts of noise at the frequencies of the harmonics and interharmonics, which can range from below 1Hz to over 2kHz. Interharmonic noise can often have random characteristics, unlike harmonic noise.

These 'non-ripple' noise frequencies in the d.c. network are not tested by EN 61000-4-17, and this booklet suggests employing the test methods in EN 61000-4-16 (see the REO booklet at [12]) to apply noise to the d.c. supply over the range 0 to 150kHz. But EN 61000-4-16 only applies common-mode test stimuli, so this booklet recommends modifying the test method to apply them in differential mode as well.

Pulsed sine wave ripple

An interesting survey of actual transients in the d.c. supply of a variety of motor vehicles is provided by [13], from the point of view of 'after-market' accessories or items plugged into the vehicles' accessory sockets (which used to be known as cigar lighter sockets). This survey shows that the tests in ISO 7637 are very relevant for the vehicles tested, but that additional tests should be done to cover all of the transient phenomena the survey found, in particular:

a) Interruptions lasting 0.5 to 1s when cranking the engine. EN 61000-4-29 addresses this with the longer durations of its short interruption tests (in low impedance test mode).

b) Sine wave pulsed ripple test, 10kHz – 10MHz at 5Vpp. This is not tested at all by any EN/IEC or ISO standards as a pulsed disturbance test, but as a continuous disturbance it is tested by EN 61000-4-16 (up to 150kHz), EN 61000-4-6 (150kHz to 80MHz) and EN 61000-4-3 (80MHz to 1GHz), see the REO booklets on these at [12].

Most equipment covered by the EMC Directive will have been tested to EN 61000-4-6 and EN 61000-4-3 anyway under its relevant product or generic immunity standards, so this booklet recommends that the EN 61000-4-16 tests are also applied. But as was mentioned earlier in the section on mains harmonics and interharmonics – EN 61000-4-16 only applies common-mode test stimuli, so this booklet recommends modifying its test method to apply them in differential mode as well.

EN 61000-4-6 and EN 61000-4-3 use 1kHz sine wave amplitude modulation at 80%, which is close enough to a pulse at 1kHz to avoid the need for a pulsed (on/off) test. But the frequency of the pulses (or sine wave modulation) could be very important for the immunity of equipment. This was discussed in detail in the REO booklet on EN 61000-4-3 [12].

The most cost-effective TARL method is to discover the susceptible frequencies of the EUT by analysis or testing, then to test over the full range of conducted and radiated radio frequencies using test stimuli that are modulated at the EUT's susceptible frequencies, instead of (or as well as) at 1kHz. Where the susceptible modulation/pulse frequencies are not known, 'chirp' modulation techniques are usually employed. The chirp is a slowly rising modulation frequency that covers the full range that the EUT might be susceptible to.

To save time when testing radiated RF, avionics companies often test in a reverberation chamber instead of an anechoic chamber. This means that they do not have to repeat the test on all four sides of the EUT with antennas polarised horizontally and vertically (making eight tests in all).

Repeatability and TARL issues concerning the test generator's impedance

EN 61000-4-29 does not specify what the test generator's output impedance should be from moment to moment during a short interruption test. It says it should be "…predominantly resistive…" and low even during the switching of the output voltage, but no other specifications are given. The peak inrush current specifications imply a maximum generator source impedance of just under 0.5Ω, but no guidance is given on determining the negative peak inrush current, when the EUT sources current to the test generator during a low impedance short interruption test.

An impedance of 0.5Ω is equivalent to 60 metres of copper send/return conductors each with a cross-sectional area (CSA) of 4mm^2 (that is: 120m for the power current's round trip). This may be a reasonable impedance for some types of d.c. sources, or when the length of cable between the item of equipment and the d.c. supply is very long and does not have a very large CSA.

But some batteries have much lower internal impedances, for example a 12V automobile battery with a rated starting current of 100A has an internal impedance of 0.12Ω and some (e.g. in some types of four-wheel drive vehicles) are rated for starting currents of 400A or more, so can have internal impedances of 0.03Ω or lower. The storage capacitors in an off-line d.c. power supply will have equivalent series resistances (ESRs) measured in tens of milliohms. So it is clearly possible for the d.c. power network's source impedance to be less than the (just under) 0.5Ω assumed by EN 61000-4-29, depending on the CSA and length of cable used to connect to the equipment concerned.

0.5Ω could also be on the high side for many faults in d.c. networks, especially if they occur within a few metres of an item of equipment. For example, a short-circuit at a distance of 5 metres (as measured along the d.c. power cables) could have an impedance as low as 0.21Ω when the d.c. conductors have a CSA of 1mm^2; 0.04Ω with 4mm^2 or 0.016Ω with 10mm^2. So it is clearly possible in real life for a d.c. fault to experience a much higher negative peak inrush current (out of the EUT) than might have been tested by a test generator that was compliant to EN 61000-4-29.

There are two possible consequences that follow from the test generator impedance specifications (or lack of them) in EN 61000-4-29…

- There could be variations in EUT immunity performance when tested with different generators despite the fact that they are all 'compliant with EN 61000-4-29'.
- EN 61000-4-29 tests might not represent TARL – so equipment might pass its compliance tests only to suffer interference problems in real operation.

This booklet recommends that the test generator may need to have an output impedance that is much lower than 0.5Ω to properly simulate the impedance of its d.c. supply network, depending on the intended application. As a result, the peak inrush current supplied by the generator may need to be increased above the specifications in EN 61000-4-29. For example, if the d.c. supply is powered by a battery with a cranking current rating of 600A, the 50A specification (inrush current at 24V) for the test generator in EN 61000-4-29 is clearly not representative of real life.

This booklet also recommends that the test generator has an output impedance of no more than 0.01Ω during low impedance short interruptions tests. In applications where the CSA of the d.c. cables connected to the equipment could exceed 10mm^{2,} the generator impedance should be even lower, maybe as low as 0.001Ω.

Repeatability and TARL issues concerning the peak inrush current specification

Annex B describes test methods for the inrush current of EUTs in the case where the test generator does not comply with the maximum peak inrush current specification in Clause 6. But where a test generator meets the peak inrush specification of Clause 6, the actual peak inrush that would be drawn by the EUT in real life is not considered.

As was mentioned earlier, some 12V and 24V d.c. networks powered by batteries can output peak currents that are much higher than the specification (e.g. 400A instead of 50A), and the peak current output from a large capacitor or supercapacitor can be measured in kA. The inrush limits in Clause 6 may be acceptable when trying to create a test standard that does not require very expensive test equipment – but they might not achieve TARL.

Another omission from the test generator specification in EN 61000-4-29 (Clause 6 and Annex B) is the *duration* for which the peak inrush current specification should be able to be maintained. Only a peak value is given, and it does not say whether it should be able to maintained for as little as 10µs or as long as 10s. And there is no specification that covers the ability to supply the lower levels of inrush current that follow the peak. These issues could cause there to be differences between the test results when the same EUT is tested on different 'EN 61000-4-29 compliant' test generators.

This booklet recommends that for TARL, the test generator should be able to provide the whole envelope of the EUT's inrush current, plus a margin of 30% (both in current amplitude and duration). With some types of d.c. networks (e.g. ones powered from portable batteries) it may be easiest to simply use the real-life d.c. source in the test generator for the EN 61000-4-29 tests. (Note that these cannot be claimed to be 'full compliance' tests if the d.c. source doesn't comply with the specifications in Clause 6.)

Where the real-life d.c. source cannot be used, Clause B.2 in Annex B describes how to measure the peak inrush current of an EUT by using a current transducer and an oscilloscope. It is a simple matter to extend Annex B to measure the magnitude versus duration of the inrush current demand. (The d.c. source used for this inrush current measurement should be representative of the actual d.c. source the equipment will be powered from in real ife.) This data can then be used to size the test generator so that it can supply at least 30% more than the EUT needs, both in magnitude and duration.

Repeatability and TARL issues concerning test generator switching time

Voltage dips or short interruptions can cause transient overvoltages to appear at the EUT's mains input terminals, and these can sometimes be a cause of interference. EN 61000-4-29 requires such transients to be monitored and recorded in the test report, but does not require any action to be taken on them.

A test generator with rise/fall times near to 1µs is much more likely to cause high levels of transient overvoltage than one which is closer to 50µs. This could result in significantly different test results when the same EUT is tested by different models of test generator even though they are all 'fully compliant with EN 61000-4-29'.

A real-life short-circuit can occur within a few nanoseconds, so to help design the most reliable equipment this booklet recommends testing with generators that switch the fastest, preferably much faster than even the minimum switching speed of 1µs specified in clause 6 of EN 61000-4-29.

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.

Continuing the above example: if an equipment is installed in a location where there is a high level of continuous RF field, it may be perfectly well able to cope with that threat, but it may become unreliable in that environment when any fast transients appear on its mains lead, as they will very often. 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. an RF field, RF noise on the supply, mains waveform distortion, magnetic fields, etc.) its immunity to transient disturbances – such as dips and short interruptions in its d.c. supply – 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.

The likelihood of two *transient* events happening at the same time is usually very small, and often not worth worrying about except where high levels of safety integrity are required [10].

If it is suspected that voltage dips, short interruptions and variations in a d.c. power supply could be a cause of 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 unbalances that have occurred over that period. It is rare to know exactly what the cause of a problem is, so it is normal to survey a number of other power quality parameters, as well as unbalance, to try to correlate power 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 instruments 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 is most likely to have caused the fault.

Where the failing equipment cannot be monitored, 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.

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.

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 power 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 power 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 61000-4-29 may not be able to give 100% confidence that 'full-compliance' tests to EN 61000-4-29 would be passed. But such 'non-compliant' tests may actually be better than full testing to EN 61000-4-29 for improving the reliability or safety of a equipment – as discussed in the previous section – if they 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 d.c. voltage dips, interruptions and 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 61000-4-29.

Important Safety Note: Always take all safety precautions when working with hazardous voltages, for example greater than 25v RMS a.c. or 35V peak or d.c. 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 *any* 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 61000-4-29 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 61000-4-29 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 used in a number of locations or sites.

Correlating alternative test methods with EN 61000-4-29

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 61000-4-29 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 61000-4-29 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 61000-4-29, 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 61000-4-29 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'

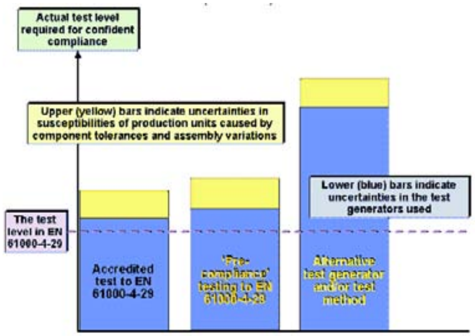
Even having EN 61000-4-29 fully applied by the same accredited EMC test laboratory cannot guarantee that a given EUT will be exposed to *exactly* the same stimuli each time it is tested. But if EMC enforcement agents test an item of equipment, they are unlikely to use the same test laboratory or model of test generator that was used by its manufacturer. So, an 'engineering margin' is recommended, because…

- There might be variations in the actual test stimuli produced by different models of generators when testing the same EUT (a number of possible causes of different test results between different models of 'compliant' test generators were discussed earlier);
- There can be variations in the test methods, even when applied by the same staff at the same test laboratory, leading to different results;
- Serially-manufactured equipment have variable immunity performance due to component and assembly tolerances (e.g. variations in the routes taken by cables or cable bundles, in some types of equipment, might make them more likely to pick up magnetically-coupled noise from currents in the d.c. supply).

So, when testing an item of equipment to EN 61000-4-29 in a fully compliant manner, it is recommended that additional tests with higher levels and longer durations of voltage dips; longer short interruptions; and larger voltage variations are performed, with the equipment still meeting its required functional performance specifications. This will not cover the repeatability problems associated with generator impedance or current capability 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 61000-4-29 tests, so how (or if) a manufacturer tests for voltage fluctuations is entirely optional. But if EN 61000-4-29 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 61000-4-29 for demonstrating compliance. A larger engineering margin is recommended, at least. But how much larger is very 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 drawn 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

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[2] EN 61000-4-29:2000, "*Electromagnetic Compatibility (EMC) – Part 4-14: Testing and measurement techniques Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests*". (Note: the BS version of the same EN is dated 2001)

[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.

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[7] 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.

[8] "*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.

[9] "*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.

[10] "*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.

[11] *"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.

[12] 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.

[13] "*Transient Test Requirements for "e"-Marking – Necessity or Bureaucracy?*", James Gordon-Colebrooke and Alex McKay, Automotive EMC Conference 2003, 16th November 2003, available from: sales@3ctest.com.

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Keith Armstrong from Cherry Clough Consultants

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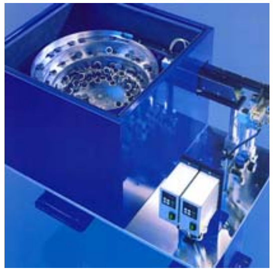
REO - Market Sectors



Automation Systems

Controllers for vibratory feeders

Communication Systems

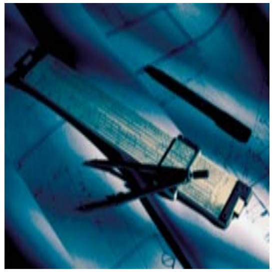
Field bus and gsm

Train Systems

Chokes and high frequency transformers

Inductive Components

Chokes, resistors and transformers

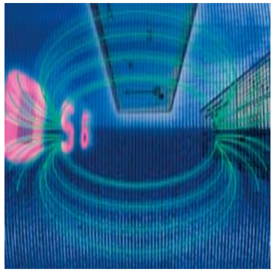


Classics

Rheostats and variacs

Renewable Systems

Solar transformers

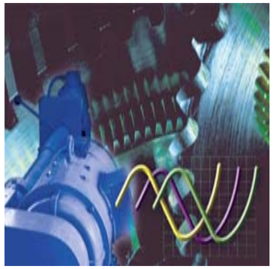


Test Systems

Power supplies and load banks

Power Electronics

Phase-angle and frequency controllers



Motor Control Systems

Soft-starts

Drive Systems

Filters and braking resistors

Medical Systems

Medical Transformers