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Handbook on EN 61000-4-14: Mains Voltage Fluctuations

Helping you solve your EMC problems

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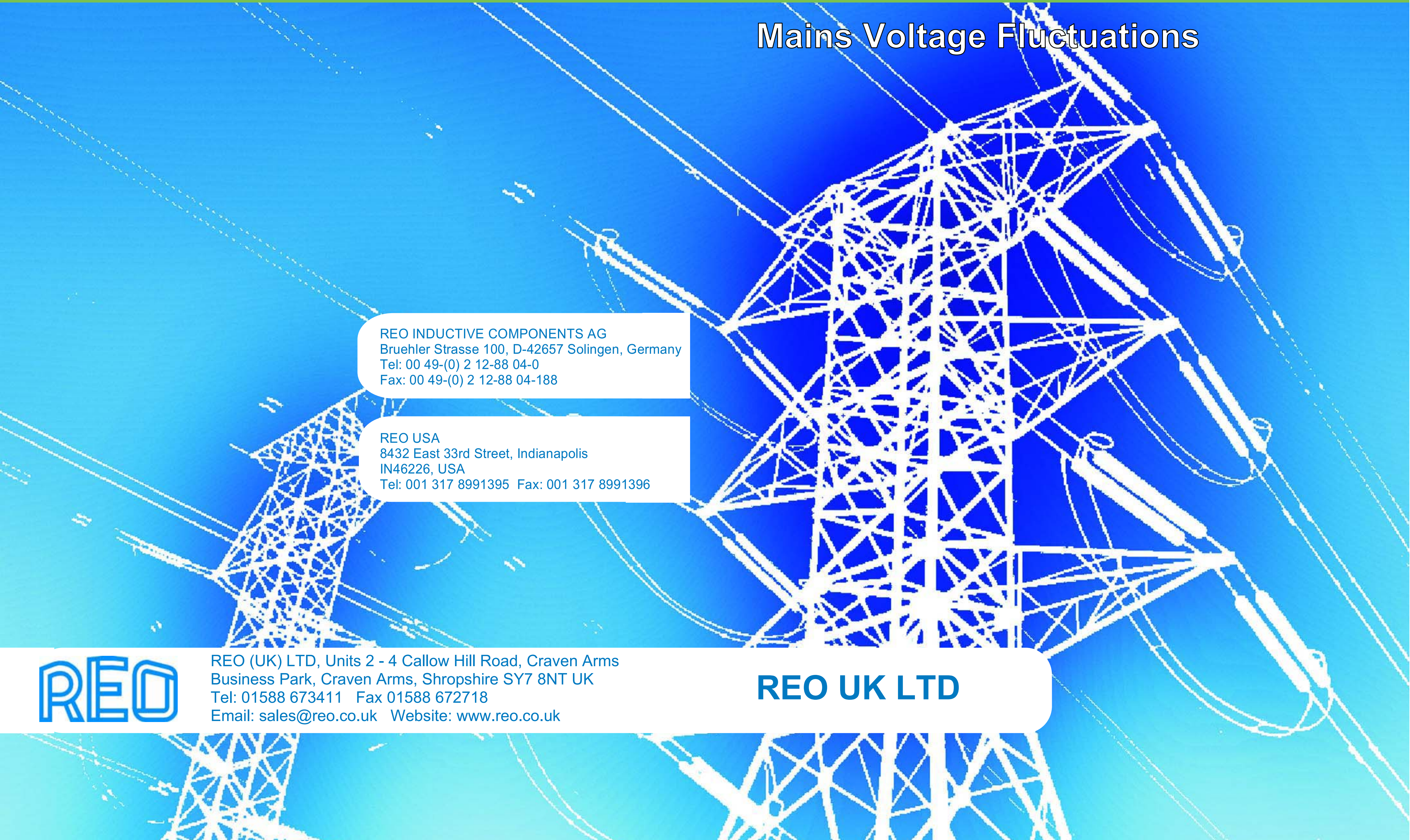
Handbook on EN61000-4-14

Mains Voltage Fluctuations



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EN 61000-4-14 and compliance with the EMC Directive

According to some experts, the effect of poor a.c. mains supply quality on electrical and electronic products is the most significant cause of downtime and financial loss worldwide. Since disturbances in the mains supply voltage are commonplace, and since they can interfere with every kind of electrical and electronic device, equipment or system (called products in the rest of this handbook) that operates from a mains electricity supply, it makes good sense to test such products with mains disturbances to ensure they will work as intended in real life. This is especially important in applications where the operation of a product can have an impact on financial or safety risks.

This booklet covers repetitive variations in the mains supply voltage, known as 'voltage fluctuations', and describes the relevant immunity test standard EN 61000-4-14. Many other power quality issues are addressed by other EN/IEC standards, and discussed and described in other REO booklets. EN/IEC 61000-4-30 [4] describes some power quality measurement techniques.

The basic immunity test method for a.c. mains supply voltage fluctuations is IEC 61000-4-14 [1], which has been adopted as the harmonised European standard EN 61000-4-14 [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].

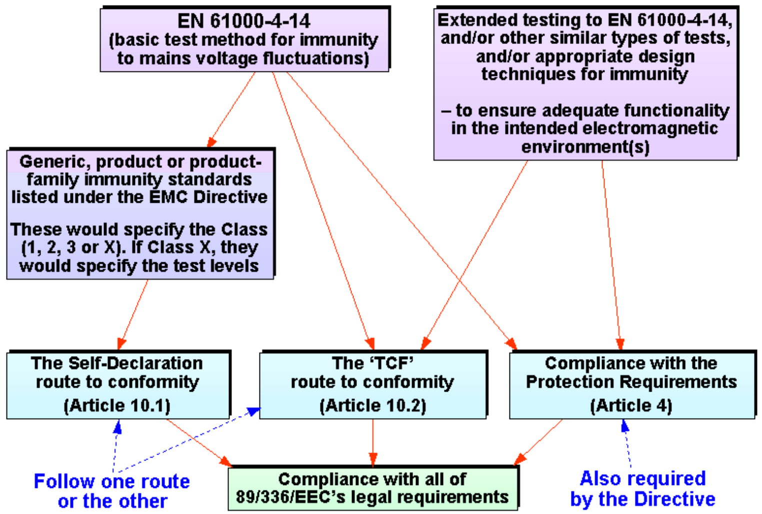
The EN version of 61000-4-14 is technically identical to the IEC document, so this booklet is of use where either standard is required. Since many national tests outside the EU, or purchasing contract requirements are based on IEC standards, this booklet may also be of use in such situations.

EN 61000-4-14 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 product'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 61000-4-14 as a test *method*, but it is always the generic or product-family standard that sets the minimum mains voltage fluctuation test *levels* and test *durations* 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 the EMC Directive [3] are known to require testing to EN 61000-4-14. But future standards (or versions of existing standards) may well do so, especially for industrial equipment and equipment intended for use in electricity generating plant.

When using the Technical Construction File route to conformity with the EMC Directive (Article 10.2 in [3]) it is possible to use EN/IEC 61000-4-14 directly, in which case it *should* be listed on the product's EMC Declaration of Conformity. In such cases the product manufacturer should assess the EM environment of the product 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]).

The relationship between EN 61000-4-14 and the first edition of the EMC Directive (89/336/EEC)



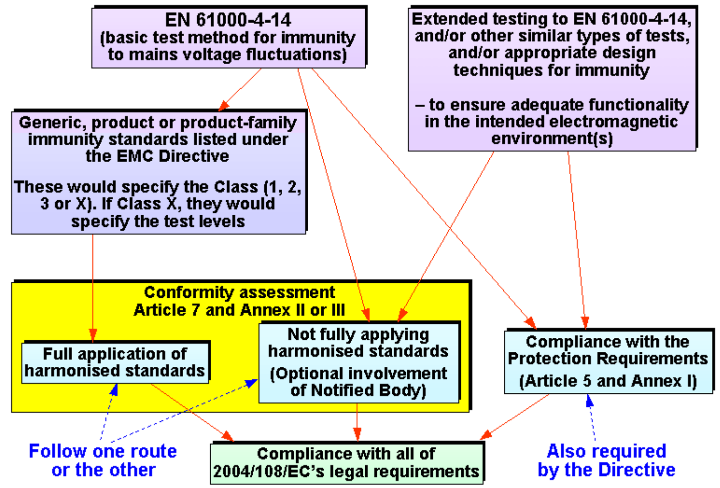
Compliance with the EMC Directive's Protection Requirements applies *in addition* to the requirement to follow one of the conformity assessment routes (Self-Declaration, Article 10.1; TCF, Article 10.2; or Type Approval, Article 10.4 of [3]). Products that pass tests to all relevant product or generic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

So, where a product could be affected by mains voltage fluctuations in its normal operating environments, it may prove necessary to test using EN 61000-4-14 or similar tests in order to comply with the EMCDs Protection Requirements.

Applying EN 61000-4-14 or similar immunity tests which go beyond the minimum requirements of the EMC Directive's listed product and generic standards can also be a way to help make products 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. Products that are 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).

The relationship between EN 61000-4-14 and the second edition of the EMC Directive (2004/108/EC)



Under 2004/108/EC, 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 61000-4-14 at specified levels could be a requirement imposed by a purchaser to help ensure that a particular 'fixed installation' complies with the EMC Directive's Protection Requirements.

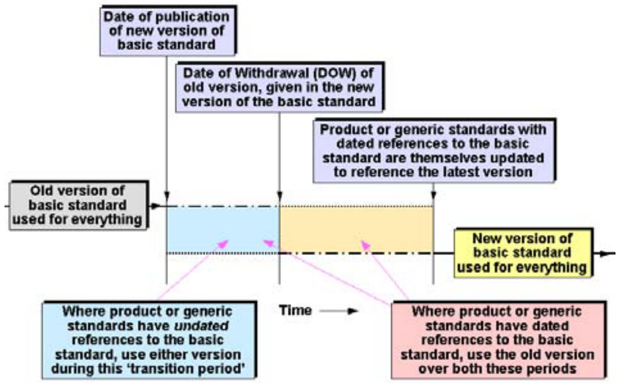
EN 61000-4-14 applies to all equipment with a rated input current of up to 16A per phase, powered from public or industrial power supply distribution networks that provide a.c. 'mains' power at any frequency other than 400Hz. These mains power networks will almost always operate at either 50 or 60Hz, although some transportation systems run on 16⅔Hz.

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 voltage fluctuation test standards based on their own particular kinds of a.c. or d.c. power supply networks. For instance, 'central office' telephone equipment is supplied at 48Vd.c.; motor vehicles are supplied at 12, 24, and even 42Vd.c., and aircraft engines generate power at 400Hz – and all of these supplies can suffer from voltage fluctuations.

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

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

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



This booklet describes how to apply EN 61000-4-14:1999. 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 61000-4-14:1999"), or an undated reference (e.g. "EN 61000-4-14"). 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. (There are no other versions of EN 61000-4-14 other than the 1999 one, at the time of writing.)

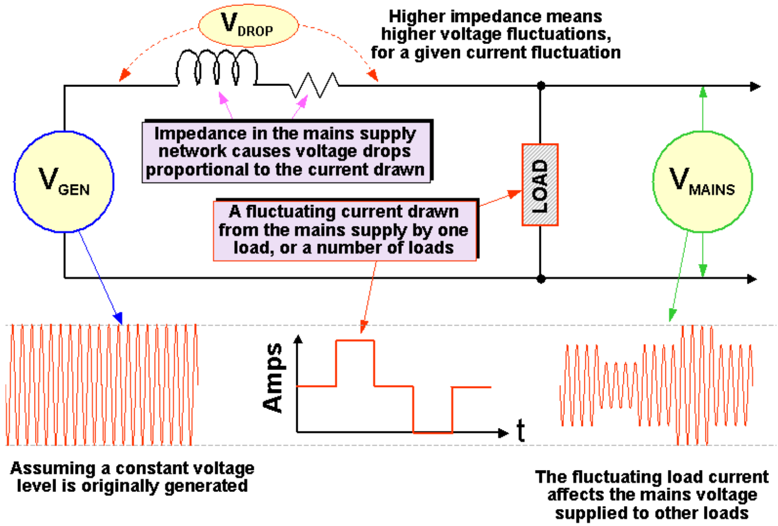
But it is clearly impractical for manufacturers to rush to test labs to retest all of their products on the very day a new version is issued, so each new version of an IEC standard includes a date on which it supersedes the previous version. This is the "date of withdrawal" (DOW), and provides a transition 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 products to the latest version of a standard, retesting older products 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 products are 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 61000-4-14 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 are mains voltage fluctuations, and how do they arise?

How mains voltage fluctuations are caused by fluctuating load currents



The common usage of the phrase 'voltage fluctuation' can mean any kind of change from the nominal value of a voltage, from extremely slow (e.g. 0.0001Hz) to very fast (e.g. 1MHz) changes. But EN 61000-4-14 uses the definition from the IEC's International Electrotechnical Vocabulary: a "*series of voltage changes or a cyclic variation of the voltage envelope*", and this is the essence in which this phrase is used in this booklet.

When considering lighting, mains voltage fluctuations cause what is generally known as 'flicker' – variations in the level of lighting that are perceptible by the human eye. The levels of emissions of voltage fluctuations from products are limited to some degree by EN/IEC 61000-3-3 and EN/IEC 61000-3-11, which cover the frequency range from 0.001Hz to 40Hz. But EN 61000-4-14 only tests with voltage fluctuations that occur at the rate of 0.2Hz.

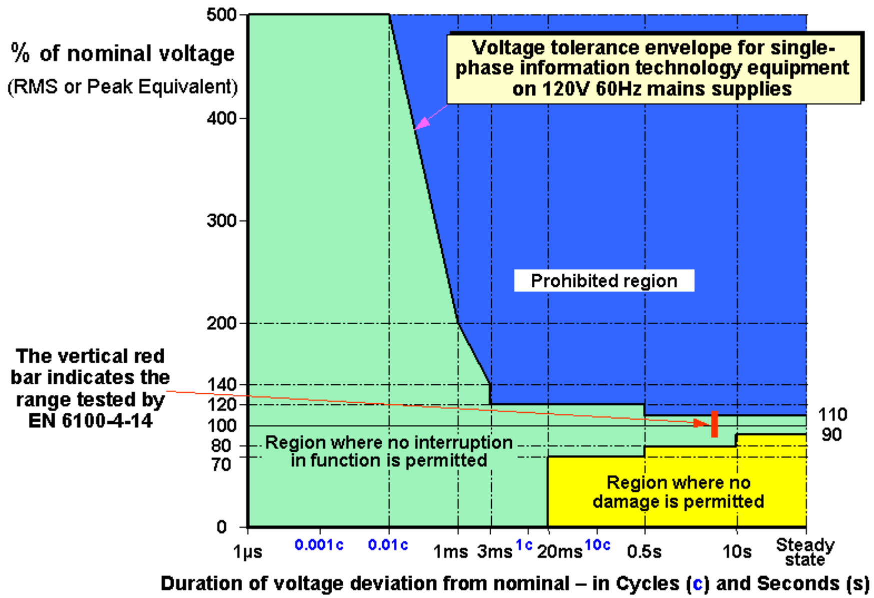
There are two chief causes of fluctuations in the mains supply voltage….

a) Fluctuating currents in the mains supply distribution network

b) The operation of the mains supply generation and distribution network (e.g. tap voltage regulating transformers)

Mains power supply networks inevitably have a complex impedance, usually having a modulus of under 2Ω at 50Hz. When loads connected to the mains power network consume fluctuating currents, the impedance of the network causes the mains voltage that is delivered to fluctuate accordingly. In general, the lower the impedance of the mains power network, the lower will be the voltage fluctuations created by a given current fluctuation.

The ITI (CBEMA) Curve (2000 revision)



Heavy loads on the mains power network are the most likely to cause significant voltage fluctuations, and EN 61000-4-14 lists the following examples of causes of continuous but randomly varying loads…

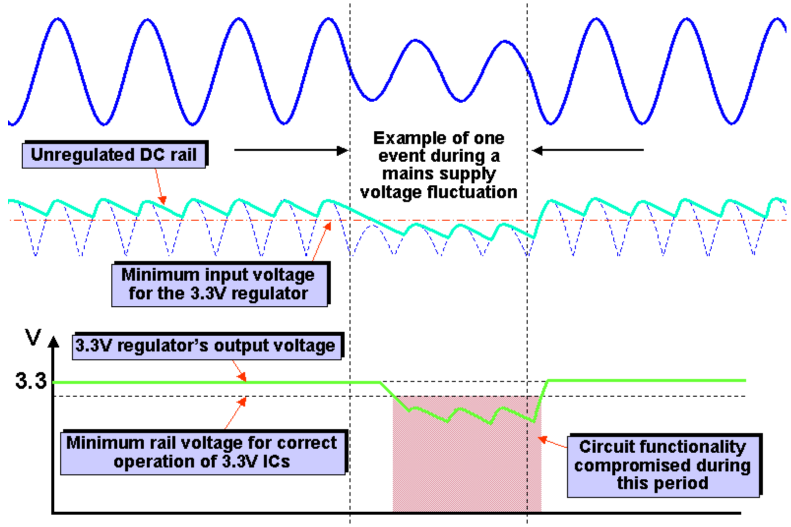
- Resistance welding machines
- Rolling mills
- Large motors with varying loads
- Arc furnaces
- Arc welding plant

EN 61000-4-14 also lists the single on/off switching of electrical loads, such as motors. A number of loads switched on or off one after another would cause a repetitive change in the mains voltage. The loads could have a similar effect whether they were all in one place, or scattered around the mains network.

As the loading on the mains supply network changes, automatic equipment operates to maintain the voltage within specified limits (in the U.K. this is 230Va.c.rms -6% +10%). Repetitive operation of this equipment, maybe in response to a fluctuating load current or a malfunction, can cause repetitive changes of the mains supply voltage – voltage fluctuations.

The "ITI (CBEMA) Curve" and its Application Note [6] describe an AC input voltage envelope for 120V 60Hz mains power networks, which typically can be tolerated (no interruption in function) by most Information Technology Equipment (ITE) in the USA. The ITI Curve and its Application Note make it very clear that it is not intended to be used as a specification of the mains power quality – or as a specification for designing products but despite this it is often employed in these ways.

An example of how a decreasing mains voltage fluctuations can cause problems in electronic circuits (example of a 3.3V d.c. circuit)



EN 61000-4-14 lists the following problems that can be caused by voltage fluctuations…

- Degradation of performance in equipment using storage devices (e.g. capacitors)
- Instability of internal voltage and currents in equipment
- Increased ripple
- Loss of function in control systems

A further possibility is…

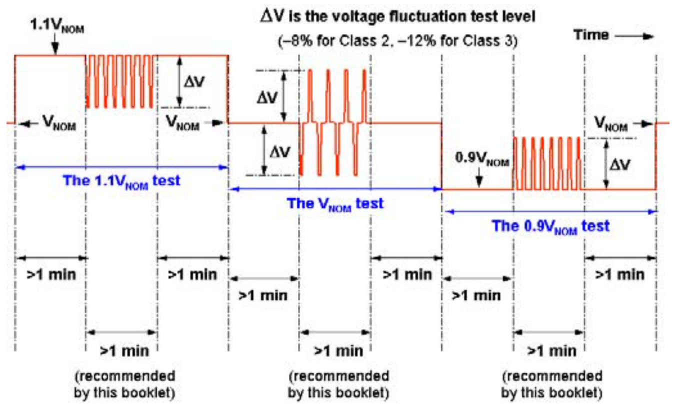
- Interference with low-frequency measurements and signal processing (below 50Hz)

The first three points above focus on the quality of the d.c. power that is converted from the mains supply and used in electronic products. Mains voltage fluctuations will cause a ripple on an unregulated d.c. power 'rail', that will and could interfere with their operation. Some circuits operate from regulated d.c. rails – but the problem here is that the changes in the unregulated voltage might be enough to effect the voltage of the regulated rail.

Some power supply circuits (whether linear or switch-mode) might be made to go unstable when their control loops are excited by the fluctuations in their unregulated d.c. rails. This could cause the error in the regulated d.c. voltage to be much larger than would be expected given the change in the mains voltage.

The power supply ripple, and the fluctuating magnetic and electric fields (for example, near cables and mains transformers) caused by the mains voltage fluctuations could couple into circuits and long measurement leads and disturb them directly. This is more likely to be a problem for circuits that measure or control small signals, especially if those signals lie in the d.c. to 50Hz range.

An example of a complete test (a series of three types of test)
(not drawn to scale, wrong number of fluctuations shown in each test)
(derived from Figure 2 of EN61000-4-14)



Introduction

This booklet is not a complete recital of everything that is in EN 61000-4-14, 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 waveform

Three different types of voltage fluctuation test are used, one after the other, to test a product (known as the Equipment Under Test or EUT), as shown by the nearby figure. Each of the three types of voltage fluctuation tests begins with at least 1 minute of conditioning at a steady mains supply voltage, then applies the voltage fluctuation, then finishes with another minute at the original steady voltage.

The durations of each of the three types of voltage fluctuation are not specified in EN 61000-4-14, but this booklet recommends that they should each last for at least 1 minute.

The three types of voltage fluctuation test are as follows…

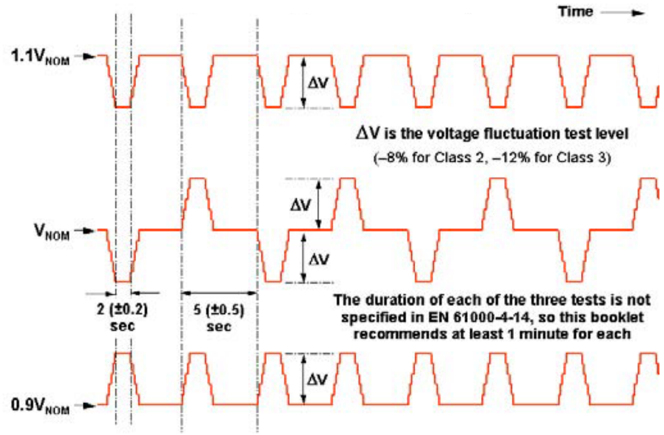
1) The supply voltage is set to 90% of the nominal mains voltage (e.g. 207Vrms when the nominal is 230Vrms) and the voltage fluctuations are all increasing, with level ΔV.

2) The supply voltage is set to 100% of the nominal mains voltage (e.g. 230Vrms when the nominal is 230Vrms) and the voltage fluctuations are alternately increasing and decreasing, each with level ΔV.

3) The supply voltage is set to 110% of the nominal mains voltage (e.g. 253Vrms when the nominal is 230Vrms) and the voltage fluctuations are all decreasing, with level ΔV.

The three tests apply the ΔV fluctuations to different initial mains voltages: 90%, 100% and 110% of nominal – but where the 90% and 110% supply voltages would go outside the manufacturer's specification

The three types of voltage fluctuation test
(not drawn to scale)
(derived from Figure 1a of EN 61000-4-14)



for a product – the ΔV fluctuations should be applied instead to the minimum and/or maximum values specified by the manufacturer.

The test level ΔV depends upon the 'Class' of the EUT (see later) and is either 8% of the nominal mains voltage (e.g. 18.4Vrms when the nominal is 230Vrms) for Class 2 products, and for Class 3 it is 12% (e.g. 27.64Vrms when the nominal is 230Vrms).

In each of the three test waveforms, the ΔV voltage fluctuation test level is maintained for 2 seconds ±10% (the 'dwell time'), and the individual fluctuations repeat every 5 seconds ±10%.

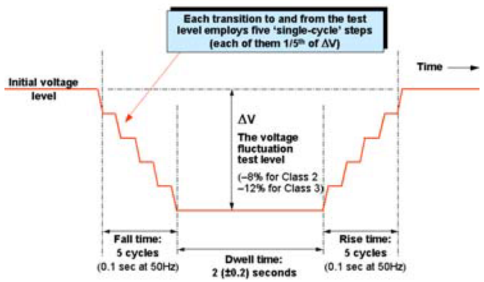
In EN 61000-4-11 (the basic immunity test standard for dips, dropouts and interruptions) the level of the mains voltage is changed instantaneously at a point when the mains voltage is passing through zero. But EN 61000-4-14 uses a more complex way of changing from the initial test voltage to the ΔV test level.

Each transition from the initial supply voltage to the ΔV test voltage (and back again 2 seconds later) occurs in a series of five small steps, each one of them one-fifth of ΔV in amplitude. For example, for Class 2 products ΔV is 8% of the nominal mains voltage, so each of the five small steps would be 1.6% of the nominal mains voltage.

Each small step occurs during a single cycle of the mains, so the transition from the initial supply voltage to the full value of ΔV takes five mains cycles to complete (for example: 0.1 seconds for a mains frequency of 50Hz). During each of these 'single-cycle' steps, the actual one-fifth of ΔV change only occurs during the last quarter, between the time that the mains waveform has reached its negative peak and when it next reaches zero (i.e. from 270° to 360°).

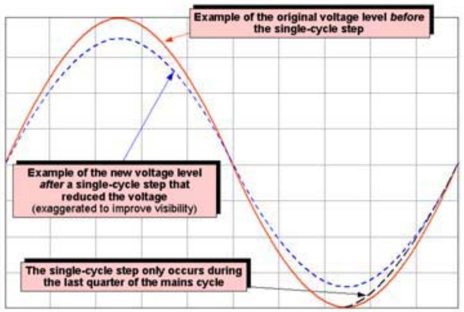
Example of an individual reducing voltage fluctuation

(not drawn to scale, derived from Figure 1c of EN61000-4-14)
(increasing fluctuations rise above the initial voltage level, but are otherwise identical)



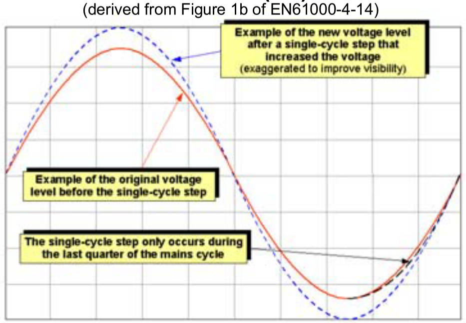
Example of a single-cycle *reducing* voltage step of 1/5th of the specified test level (ΔV)

(derived from Figure 1b of EN61000-4-14)



Example of a single-cycle *increasing* voltage step of 1/5th of the specified test level (ΔV)

(derived from Figure 1b of EN61000-4-14)



The way that the supply voltage transitions from initial to ΔV, and back again, in five single-cycle steps is very difficult indeed to achieve without a programmable waveform synthesiser, which also means that the test generator for full-compliance testing must use power amplifiers, see later.

The mains supply waveform itself is not specified, but assumed in this booklet to be a sinewave with under 3% total harmonic distortion (as required by EN 61000-3-3 for testing the *emissions* of voltage fluctuations). Of course, while the waveform is in the course of changing (during the final 90° of a mains cycle, as shown in the nearby figure) the waveform distortion would measure higher than 3%, but this is unavoidable.

Classes of equipment

Clause 5 and Annex A of EN 61000-4-14 specifies four Classes of equipment according to their likely exposure to voltage fluctuations in their mains power supplies.

But the first three of these classes only apply where products are connected directly to the Point of Common Coupling (PCC), or In-plant Point of Common coupling (IPC), with a reasonable length of mains cable that they don't share with any other products. What to do when this situation does not apply is discussed later.

Class 1

No tests are required for this class. Annex A reveals that Class 1 is for equipment that is so sensitive to mains power quality that it needs to be connected to specially protected mains power supplies, where the levels of voltage fluctuations are – *by design* – significantly less than those expected on the normal mains supplies provided to domestic properties. Uninterruptible Power Supplies (UPSs), Constant Voltage Transformers (CVTs) or Motor-Generator Sets (MG sets) are typically used when creating such protected mains supplies.

Class 2

This class is for "*equipment intended for connection to public mains distribution networks or other lightly disturbed networks*". This generally applies to domestic (residential, household, etc.) and commercial networks. Some light-industrial and industrial networks where heavy power equipment (e.g. powerful welding equipment) is not used may also fall into this class.

Class 3

Class 3 is for products connected to "*heavily disturbed*" mains power networks, which are most often industrial networks. We can distinguish such environments from those covered by Class 2 because they usually have either…

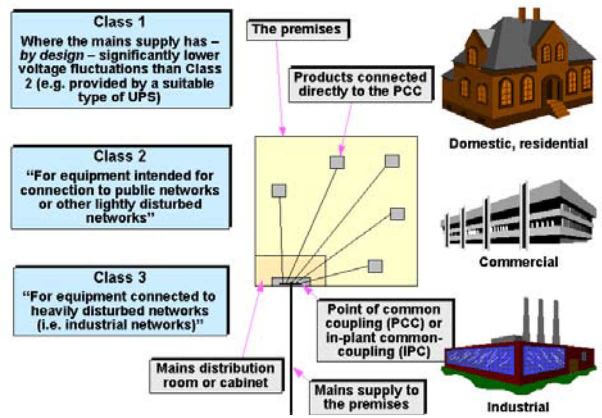
- A major part of their load fed through converters, and/or…
- Welding machines, and/or…
- Large motors or other high-power loads that are frequently started, and/or…
- Loads that vary rapidly.

Some *commercial* premises use high-power fluctuating loads, for example the lighting and stage scenery machinery used in some theatres for live stage shows, mobile 'pop concert' installations, etc., in which case Class 3 might be appropriate.

Class X

All of the tables in EN 61000-4-14 that specify the Class 1, 2 and 3 tests have a column for Class X that is filled in every case with the letter 'x'. This signifies that each of the Class X specifications can be chosen at will by the product or generic standard committee, or by the purchaser (usually in the technical specification that forms part of the contract with his supplier, often based on a power quality survey of a particular site).

The various Classes of product defined by EN61000-4-14



EN 61000-4-14 seems to be intended to apply to mains power distribution networks, whether public or industrial, in developed countries. But, as discussed later, some equipment may be expected to be powered from less-than-ideal mains networks that exist in some countries; from local generation and/or from so-called 'green power' supplies – all of which can have voltage fluctuations that are bad or worse than Class 3. When specifying equipment for such applications, the Class X in EN 61000-4-14 can be very useful.

Issues concerning PCCs and IPCs

The tests levels set by clause 5 of EN 61000-4-4 assume equipment is connected to a PCC or IPC. The PCC in a domestic house would be the 'consumer unit' (more usually called the 'fusebox' or the 'meter cupboard' by the residents). In a large commercial building or industrial plant the PCC or IPC would usually be in a dedicated room, often called the switchgear or distribution room.

The reason that the standard assumes products are connected to a PCC or IPC is that the standards committees only have figures for the voltage fluctuations that occur in the mains distribution networks themselves. Beyond the PCC or IPC thestandards committee can not predict what voltage fluctuations might occur, because they do not know what cable impedances are being used to power the loads, and they don't know if different products are sharing the mains supply on the ends of a long cable, far away from a PCC or IPC.

For example, domestic premises in the UK use 'ring main' supplies, in which large numbers of electrical and electronic equipment can be powered from a single cable that loops around the building and connects to the PCC at both of its ends. The aim of this is to reduce the cost of the copper used in a building, but a product connected along such a ring main can suffer from worse power quality than if it had its own direct feed from the PCC.

Clearly, where a product is powered from a mains cable that also supplies a fluctuating load, the levels of voltage fluctuation it experiences could be worse than those expected at its PCC or IPC. It is even possible for a single product that consumes very heavy fluctuating currents, and is connected to the PCC or IPC by a long mains cable, to give rise to voltage fluctuations that cause it to interfere with itself!

So where products are powered from a PCC or IPC by cables long enough to add significantly to the impedance of their mains supply, and/or when products share such long mains cables with other products, it is possible for the levels of voltage fluctuations to be higher than those specified in EN 61000-4-14 for the appropriate Class.

EN 61000-4-14 says that in such cases the test levels to be applied should be agreed on, presumably between the purchaser or specifier and the supplier. Products in what would normally be onsidered a Class 2 environment might need to be tested to Class 3 or higher (using Class X and specifying the test levels).

Likewise, products in what would normally be considered to be a Class 3 environment might need to be tested to Class X using specified test levels higher than Class 3.

Comparison with EN 61000-4-11

Mains voltage fluctuations are similar in some ways to mains voltage dips, for which the basic test standard is EN 61000-4-11. But the dips tests in EN 61000-4-11 are single events, only utilise decreasing mains voltage levels, and are only applied to a nominal mains voltage.

Although the amplitude of the changes in the mains voltage used in EN 61000-4-14 tests are smaller than those used by EN 61000-4-11, they are applied when the mains voltage is both lower and higher than nominal, and they are repetitive (cyclic). So they explore different aspects of a product's electromagnetic immunity.

The test generator

Clause 6 and Table 2 of EN 61000-4-14 specify the characteristics of the test signal generator, and these specifications will not be repeated here. The generator with power amplifier specified in EN 61000-4-11 is said to be suitable, providing it can achieve an output that is 25% above nominal mains voltage.

Basically, the test signal generator consists of a programmable waveform generator amplified by a power amplifier to synthesise a mains waveform. The waveform generator is programmed to produce signals corresponding to the hree types of voltage fluctuation test described earlier. These signals are amplified by the power amplifier and used as the mains source to power the EUT.

It is easy to set-up a suitable test generator using laboratory bench equipment: for example an arbitrary waveform generator feeding a suitably-rated power amplifier, but some test equipment manufacturers supply single-box solutions with all the pre-programmed test waveforms and on-screen user interfaces to make them easy to use for EN 61000-4-14 testing.

Note: Power amplifiers intended for audio use are usually not suitable as mains power sources, even if they appear to have suitable voltage and power ratings – as the author can attest from bitter experience. And they usually don't like driving the EUT via a step-up transformer either. Always use a power amplifier that is designed to be used as a laboratory AC source with the required output voltages and power ratings when driving full power into any non-linear or reactive load. Suitable equipment will usually have too much distortion to be used as audio power amplifiers.

Modern mains synthesisers almost always use pulse-width-modulated switch-mode techniques in their power amplifiers to generate their output signals, and as a direct result their power inputs and outputs can contain huge levels of noise at frequencies from a few kHz to many hundreds of MHz – but EN 61000-4-14 does not specify the amount of noise that is 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 mains network. They should also have low levels of noise on their synthesised power outputs so that they are unlikely to interfere with any type of EUT and confuse the results of the test. Very effective radio frequency (RF) suppression will generally be required at the mains power inputs and synthesised power outputs of PWM-based EN 61000-4-14 test generators.

Verifying the test signal generator

Clause 6.3 of EN 61000-4-14 states that the generator's characteristics should be verified against Table 2, with the EUT connected. Since there are many different types of EUT, this implies that the generator performance should be verified each time an EUT is to be tested, which is good testing practice anyway.

EN 61000-4-14 does not say *how* the generator is to be verified, although Figure 3 shows a voltmeter and oscilloscope that are presumably intended for this purpose. Most test engineers should be competent at doing this verification using a calibrated oscilloscope and true-rms voltmeter.

Safety Note: When measuring mains voltages or currents, only use probes and equipment that are approved by an independent safety testing body (e.g. BSI, VDE, TUV, UL, CSA, etc.) 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 mains electricity – don't let it be you!

The test set-up

The test set-up is specified in Clause 7 and Figure 3 of EN 61000-4-14, and is very simple. Basically, the synthesised mains power outputs from the test generator are simply connected to the mains power inputs of the EUT.

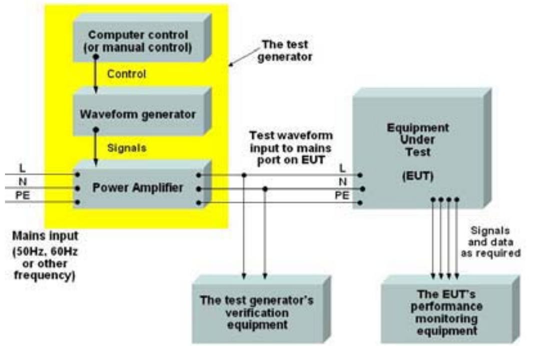
Because this test does not use RF it is possible to perform it anywhere, with almost any variety of physical arrangements, and still achieve correct results. This makes it a test that it is easy and low-cost for a manufacturer to perform, since it does not need shielded rooms, anechoic chambers, costly 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 auxiliary equipment required to make the EUT work correctly, if the method used will not affect the outcome of the voltage fluctuation test.

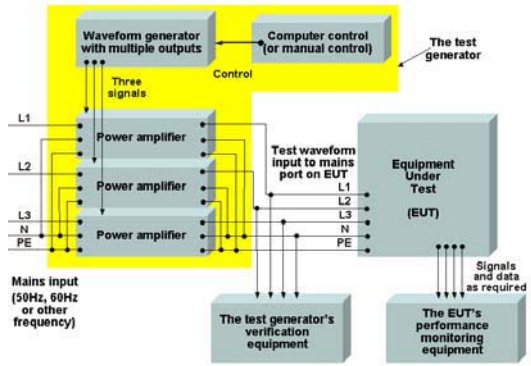
Test conditions and test plan

Clause 8.1.1 of EN 61000-4-14 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.

Example of a test set-up for a single-phase EUT



Example of a test set-up for a 'three-phase + neutral' EUT



REO can create custom loads to meet any requirements

Clause 8 requires a test plan to be prepared before starting to test an EUT. It is always a good idea to create a test plan well beforehand anyway, to help identify testing requirements ahead of time, to avoid wasting time sorting out unforeseen problems whilst paying premium test laboratory rates.

A *recommended* list of test plan contents is given in clause 8, but this list is not mandatory (although some sort of test plan is required for full-compliance testing). This list is not repeated here (refer to [1] or [2]) – but it is a very basic list and it would be hard to argue against omitting any of the listed items.

Clause 8 also requires that monitoring equipment is provided to measure the functional performance of the EUT during and after the tests (discussed in the next section). It is very important for a test plan to determine what monitoring equipment is required, and how it needs to be set-up and used, to make sure that it is all made ready in advance to help avoid wasting time during testing.

EN 61000-4-14 does not mention a rather obvious fact the electromagnetic (EM) environment in which the test is being conducted should not be so severe as to interfere with the EUT. Such situations make it difficult to tell whether it is the environment or the test that is causing its functional performance to go out of specification (see later). 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.

Monitoring the EUT for performance degradation during the tests

The functional performance degradation allowed during and after the tests may be specified by product-family or generic standards. Lacking these, the results should be evaluated according to clause 9 of EN 61000-4-14 (see later).

Well before the tests are begun, the functional specifications for the product should be defined, and serious thought should be given to how to monitor the product's performance during the tests – with the required levels of accuracy and repeatability to be sure whether the functional specs are actually being met.

This helps determine whether any special testing arrangements need to be organised, equipment hired, special cables and leads made up, etc., etc

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 product.

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 correct operation of the EUT is in place. The EUT is operated in its normal mode, fully loaded, and the three types of voltage fluctuation test are applied as described earlier, one after the other with the requisite conditioning periods in-between each type of test.

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 personal computer that is tested whilst running a word-processor with all of its interfaces operational and monitored for performance (e.g. Centronics, Firewire, RS232, Mouse, Keyboard, VGA, USB, etc.) will not need testing again if it is also possible to use it with a spreadsheet program. But it should be retested if it can also be used in a mode in which an add-in card controls an industrial robot via a dedicated interface.

Testing three-phase products

Three-phase products are tested with voltage fluctuations applied to all three phases at the same time, so needs a different type of test generator than the kind used to test single-phase EUTs. However, the five steps which start each of the ΔV fluctuations must have the correct phase relationship to the waveform in their phase. This means that the voltage fluctuations on each phase are applied with a small time-shift with respect to the fluctuations on the other two phases.

Evaluation of test results

Clause 9 of EN 61000-4-14 requires the monitoring of the EUT's functions during each test to be assessed against performance specifications defined by its manufacturer (or the person who requested the test). It also requires the results to be classified according to the following scheme…

a) Normal performance within the limits specified by the manufacturer, requestor or purchaser;

b) Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the EUT recovers its normal performance, without operator intervention;

c) Temporary loss of function or degradation of performance, the correction of which requires operator intervention;

d) Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

This classification is offered by EN 61000-4-14 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, which first appeared in the generic immunity standards.

Determining a PASS or a FAIL

Unfortunately, EN 61000-4-14 does not specify how to determine whether an EUT has passed or failed its tests. This is normal for the basic test standards in the EN/IEC 61000-4 series – but selling a product with a data sheet that says it achieves classification d) to EN 61000-4-14 is potentially misleading to an uninformed purchaser, and a joke to any purchaser who is familiar with the standard. Classification d) could never be associated with a PASS result, in any case.

The voltage fluctuations tested by EN 61000-4-14 can be expected to occur from time to time, so performance classifications a), b) or c) might be acceptable for a PASS result in the test report (see below), depending on the type of equipment and the functions it performed, plus the skill of the operator and whether they were always present.

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.

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 otherwise displays unacceptable behaviour – even if the issue concerned is not covered in the agreed performance specification.

Test report

Clause 10 of EN 61000-4-14 describes what is to be included in the test report, for full compliance testing. This list is not repeated here.

It is a good idea to include details of the test generator verification (see above) and a judgement on whether the test generator is 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 61000-4-14 is as easy to do as laboratory testing. 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. When not using test generators commercially available from well-known EMC test gear manufacturers, generators that use PWM techniques have the potential to emit enormous amounts of interference and very serious attention to filtering (and maybe shielding) may be required (see later).

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 61000-4-14 testing. It is also a good idea to take precautions where there is a possibility of significant financial loss being caused by the interference from on-site testing.

If the test generator has been designed well it should not emit high levels of noise at any frequency into the mains supply that feeds it, and its output waveforms (distorted mains voltages) will also be free of noise. RF suppression at the inputs and outputs of the test generator is not a small concern. Modern test generators almost always use PWM switch-mode techniques in their power amplifiers to generate their output signals, and these are very rich in RF energy (unless they have been heavily filtered inside the generator).

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 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 [7].

Examples of REO mains filters, single and three phase

An example of a low-cost shielded tent

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 equipment being tested.

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.

Examples of REO isolating transformers

Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as 230V or 400V (3-phase) electricity. 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.

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

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

The financial rewards of producing products 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 products new designs saved them £2.7 million in warranty costs *per year*.

But fully complying with <u>any or all</u> of the immunity test standards listed under the EMC Directive, or in the IEC standards catalogue, does not <u>necessarily</u> 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 product, based upon the real-life EM environment(s) it could be exposed to. In some applications it will be necessary to base the test programme on the products foreseeable EM environment(s) over its whole lifetime. This is too large a subject to discuss here – refer to [8] [9] [10] and [11] and [12].

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 fluctuations 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 and/or tougher EM 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 can hardly 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 mains voltage fluctuations 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 fluctuations 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 useless 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

Safety Note: When measuring mains 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 mains electricity – don't let it be you!

This section discusses a number of situations to show why – to have sufficient confidence in reliable, accurate or safe operation – it may be necessary to test products for their immunity to voltage fluctuations using tests that differ slightly or markedly from those described by EN 61000-4-14.

Mains voltages that vary more than ±10% or outside the manufacturer's specification

EN 61000-4-14 goes to great lengths not to operate the EUT very far outside of the mains voltage range specified by its manufacturer: +ΔV tests are applied with a supply voltage 90% of nominal mains (higher if the manufacturer's specification doesn't go so low); and -ΔV tests are applied at 110% of nominal mains (lower if the manufacturer's specification doesn't go so high).

Except for some industries – very few purchasers bother to read product manuals to see what range of mains voltage supply is specified by the manufacturer, and fewer still would have any idea about the actual minimum and maximum levels of mains voltage they are provided with. Most purchasers simply check that their nominal supply voltage lies somewhere within the range marked on the product near its mains input.

But real-life mains voltages can sometimes have minimum and/or maximum values that go beyond ±10% of nominal. One of the author's customers had a problem with a number of products they had supplied to a part of Spain, which turned out to be due to the (supposedly 230V nominal) mains voltage 'browning out' to under 180Vrms during the daytime, every Monday through to Friday. They had to modify the d.c. power supplies in the products accordingly, and probably made a loss on those sales as a result. The author has also experienced a brown out from the normal 240V to 140Vrms for eight hours, in the UK in 1998.

The ITI (CBEMA) curve [6] mentioned earlier indicates that mains voltages can fall by up to 30% for up to 0.5 seconds, and by 20% for up to 10 seconds and that for typical computer equipment in the USA: “*No interruption in function is permitted*“. The curve also shows that the mains voltage can fall below these levels for any length of time and that during this period “*No damage is permitted*”. Voltage fluctuation specifications based on this oft-referenced curve could stress an EUT much more than do the tests in EN 61000-4-14.

So it may be that the nominal, 90% and 110% supply voltages used as the basis for the three types of tests in EN 61000-4-14 do not represent the real-life mains voltages that the product will be expected to operate from. Also, there may be no reason to assume (as EN 61000-4-14 does) that when the supply is at its minimum level the ΔV fluctuations will only be increases, or that when the supply is at its maximum level the ΔV fluctuations will only be decreases.

Lower *effective* mains voltages due to waveform distortion

This booklet recommends that the EN 61000-4-14 tests are performed using sine-wave supply voltages with no more than 3% total harmonic distortion (this issue is not specified in the standard).

Many electronic products use rectifier-capacitor a.c.-d.c. power converters to generate an unregulated d.c. voltage rail. These respond to the *peak* of the mains waveform, not its rms voltage. A common problem is mains waveforms that are distorted by 'flat-topping' (caused by all the rectifier-capacitor a.c.-d.c. power converters that are powered from it). In some locations, in some countries, the mains waveshape is closer to a square wave than to a sine.

Flat-topped sine waves have a low 'crest factor' (the ratio of peak to RMS), so rectifier-capacitor d.c. converters don't achieve as high an unregulated voltage as they would on the same rms value of supply with a full sine wave.

Products are rated by the rms value of the mains voltages (for example 220-240Vac) – but when the peak value is depressed by flat-topping, a product can find its unregulated d.c. voltage rails to be a lot lower than its designers were expecting. So testing products with voltage fluctuations using good-quality sine waves may not run the product on as low an unregulated voltage as it might experience on real-life flat-topped mains supplies. For this reason, when testing products with voltage fluctuations using good quality sine wave power it might be better to use an even lower minimum voltage, to better simulate real-life conditions.

Temporarily high levels of ΔV

During maintenance or building work (for example) – welding or other high-power electrical equipment might be connected to a site's mains network at various points, maybe where high-power or fluctuating loads would not normally be expected. Or it might be that temporary power connections are made between the site and the public network, so that the mains supply has higher impedance than usual. Of course, both of these situations might occur at the same time.

Because such situations are not 'normal operation' the EMC Directive does not care whether the equipment suffers interference or not. But it might be a very important consideration for equipment that must operate with high-reliability, is mission-critical or has financial or functional safety implications.

Possible high levels of ΔV in developed nations

Even in developed countries, like those in Europe, North America and Australia, parts of the mains supply network can be found that have a much higher impedance than is normal for those countries. Usually, these areas are very remote, and have a single MV or HV cable feeding them over a long distance. In some remote parts of Australia the mains power is still supplied via a single conductor, using the earth (i.e. the soil) as the neutral for the return current, creating a very high source impedance indeed.

[13] sounds a cautionary note about worsening mains power quality. Although it focuses mainly on dips and interruptions, the reasons it gives for why they are getting worse also imply that mains voltage fluctuations should also be getting worse.

Even when the mains supply networks are low-impedance and stable, there are situations in which mains voltage fluctuations can have higher levels than those tested by EN 61000-4-14. There are IEC standards that set limits for the *emissions* of voltage fluctuations from many types of products:

- EN/IEC 61000-3-3 covers products that consume up to 16A/phase and do not require permission to be connected to a public 230/400V mains network, and came into force under the EMC Directive for products supplied in the EU after 31st December 2000.
- EN/IEC 61000-3-11 covers products that consume up to 75A/phase that are connected to a public 230/400V mains network, but subject to 'conditional connection', and came into force under the EMC Directive for products supplied in the EU after 31st October 2003.
- IEC 61000-3-7 covers products that operate from medium voltage (MV: 1-33kV) and high-voltage (HV: >33kV).

Although these three standards are helping to bring mains power quality under better control in the EU, they are not a complete solution in all circumstances for the following reasons…

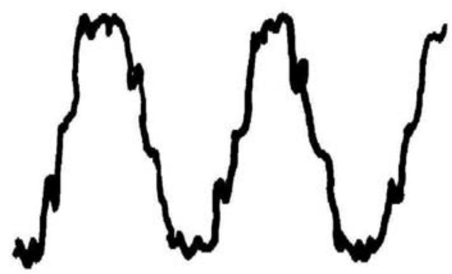
- Medical equipment is exempt from the EMC Directive, and has its own EMC standards that incorporate EN 61000-3-3 but not the other two standards above.
- Equipment supplied directly from MV or HV is not *explicitly* exempted from the EMC Directive, but the manufacturers of such equipment usually seem to act as if this is the case.
- Not everyone bothers to comply with the above EN standards when they supply products in the EU, even though they still affix the CE mark to them. This is especially true for custom-designed industrial equipment.
- EN 61000-3-3 and -3-11 only apply to equipment connected to public 230/400V mains supply networks – they don't apply to 230/400V power networks dedicated to a single user and supplied from their own dedicated MV or HV transformer (typical of large sites and heavy industry). Neither do they apply to electricity networks that are isolated from their national electricity network, by virtue of being locally generated.
- EN 61000-3-3 allows a product to emit voltage fluctuations of 3% (maybe even 4%) under some circumstances. When a number of such products are operating at the same time on the same mains network, their operational timings could allow their fluctuations to combine to cause much higher levels of fluctuations overall. Only three or four such products operating on a similar operational cycle could cause voltage fluctuations that exceed the Class 2 test levels in EN 61000-4-14.
- EN/IEC 61000-3-11 and IEC 61000-3-7 permit any level of voltage fluctuations to be emitted as long as the organisation that supplies the mains power agrees (but sometimes the suppliers are not even asked).
- IEC 61000-3-7 has never been adopted as an EN, and is not listed under the EMC Directive. Compliance with this standard is voluntary, usually by agreement between a purchaser and a supplier.
- There is a huge installed base of 'legacy' equipment that was quite legally installed before the above standards came into force in the EU, and never had their emissions of voltage fluctuations tested.

Possible high levels of ΔV in global markets

These days, many types of electrical or electronic equipment are sold to many different countries around the world. But when developing equipment in a developed country it is easy to take the high-quality mains power supply network for granted, and assume that the mains power around the world will be just as good. This assumption can be very wrong, and could lead to great expense.

For example, [14] describes the very poor quality of the mains waveform in a residential area of Israel in 2000. Although the problems described in this example were caused by waveform distortion and RF noise, they arose because equipment with high levels of emissions were allowed to be connected to a mains network that had a high impedance. High levels of voltage fluctuations and other power quality issues should be expected in such an environment.

Example of domestic mains waveform in Israel, in 2000
From Mick Maroudas PhD. 2nd October 2000, from [14]



The effects of local generation on ΔV

EN 61000-4-14 does not cover locally generated mains supplies independent of the mains network, which can have power quality that varies from very good to appalling.

Locally generated 110/230/400V power usually has a higher source impedance than is provided by a connection to LV, MV or HV power networks forming part of a national grid. A consequence of higher impedance is that the voltage fluctuations will be higher, for a given amount of load current fluctuation. Locally generated power may also permit voltage variations of greater than the ±10% assumed by EN 61000-4-14, and they may not be as stable as a national power supply network – their automatic voltage control devices may themselves cause voltage fluctuations under some circumstances, even if their loads are constant.

Many types of products may be required to operate from locally generated power from time to time, such as…

- All hospital equipment, telephone exchanges and 'internet hotels' when the emergency generators are tested (typically once per week) or when running on emergency power due to loss of the normal mains supply.
- All domestic and commercial equipment when run on emergency power due to a loss of the normal mains supply (for example, all the equipment in the author's office building usually has to run from a small standby generator for several hours, several times each year).
- Mains-powered products used in vehicles (marine, inland waterways, road vehicles including caravans, aircraft, diesel trains, etc.) and offshore oil and gas platforms which, of necessity, have to generate their own 110/230/400V mains power locally. As more and more high-power electronic power converters are used in such vehicles (e.g. marine thrusters, and even main propeller drives at several MW) the voltage fluctuations of their relatively high impedance mains networks may be expected to increase.
- Equipment used in open-air concerts, travelling fairgrounds, etc., supplied by portable generators.

The effects of 'green' power on ΔV

Premises powered by 'green' energy sources, e.g. photovoltaic; CHP (combined heat and power); wind, wave or water power are usually connected to the public mains supply via a two-way electronic power converter that can export surplus electricity to the public mains supply, and import public mains power when the green energy can't keep up with the demand of the premises.

These electronic converters could have higher output impedances than a 'normal' mains connection; so could suffer from higher levels of voltage fluctuations for given levels of load current fluctuations. Also, the automatic control of the voltage of the green power supplied to a site may not be as stable as a national power supply network, and so could suffer from high levels of voltage fluctuations even if the loads are constant.

The ability of many green power supplies to source excess energy back to the mains supply network, means that they could cause the mains voltage to rise by more than would be expected for loads that are merely energy sinks.

The number of sites powered by green energy is set to rise, as products for domestic, commercial and industrial sites become more affordable, and also due to numerous initiatives intended to help reduce global warming.

The rate of the voltage fluctuations

Mains supply voltage fluctuations can occur at any rate, or at random, but the tests in EN 61000-4-14 use a fixed rate of 0.2Hz (one voltage fluctuation every 5 seconds) and vary the amplitude (the test level, ΔV). But the actual rate of the voltage fluctuations can be significant for a products real-life reliability, for a number of different reasons.

One real-life example is a design of a sleep apnoea monitor. Apnoea monitors sound an alarm when the breathing rate becomes too low (a common problem for some children) to wake them up or summon help. A particular design used a switch-mode power supply that had a 'hiccup' mode to save power. The hiccup rate was about 1Hz, and so the magnetic fields from its power lead fluctuated at 1Hz. Unfortunately, the circuitry that detected the person's breathing picked-up the fluctuating magnetic fields, and the resulting 1Hz noise signals were enough to cause the circuit not to sound the alarm when breathing slowed or stopped. As a direct result of this self-interference problem, a baby is known to have died.

Mains power cables, connectors, transformers, lamps and power converters all emit electric and magnetic fields in response to the waveforms of their mains supply voltage and current waveforms. Clearly, if the mains voltage fluctuates, these electric and magnetic fields will also fluctuate. Most mains-powered power converter circuits will respond to the fluctuating mains voltages, if only because the storage capacitors that follow their bridge rectifiers will draw heavier than usual currents whenever the mains voltage fluctuates in an increasing direction.

In addition, some electronic circuits will respond to certain frequencies present in the 'ripple' on their unregulated d.c. voltage rails. Mains voltage fluctuations will add ripple at the same frequency as the fluctuations – so the frequency of the mains voltage fluctuations could be important for the correct operation of the product. The feedback loops in some voltage regulators and switch-mode power converters can be susceptible to certain ripple frequencies, making them less stable.

The above example and discussion shows that the rate of the mains voltage fluctuations could be important for the real-life immunity of some products. So testing with the 5 second rate (0.2Hz) fluctuations of EN 61000-4-14, at any reasonably foreseeable ΔV, might not detect problems that could occur in real life. In the example of the sleep apnoea monitor above, a noise signal every 5 seconds would be too slow to be a viable breathing rate, so would not have prevented it from sounding an alarm.

One way of dealing with this is to perform tests to EN 61000-4-14 but to extend them by varying the repetition rate over a wide range. Rates that are slower than once every 5 seconds is easy enough, but merely altering the time between the fluctuations does not allow the rate to exceed once every two seconds (0.5Hz). Reducing the dwell time to 0.1s would allow a rate of up to 2.5Hz. Making the transition to the test level in one single-cycle step instead of five, with a dwell time of only 0.05 seconds, would allow a rate of up to 7Hz. Faster rates are possible with even greater changes to the EN 61000-4-14 test method, or the use of alternative test generators (see later).

It may be important to test the worst-case for electric and magnetic field coupling, for example by draping the mains lead near or over the product or any leads connected to it, in a way that could possibly occur in real-life. A number of different product and cable configurations, and product operating modes, might be required to test all of the possibilities.

Note that high levels of voltage fluctuation are more *likely* to occur when their repetition rates are low. The higher the frequency of the mains voltage fluctuations

– the lower the level of their fluctuation is likely to be. However, high levels at high frequencies (say, 10Hz) are not impossible and may need to be considered when very high reliability or ruggedness are required, or where the product has an impact on safety.

Testing a wide variety of fluctuation frequencies could be very time-consuming, and it is possible to limit the testing time by testing only those frequencies for which the products is known to be susceptible. These frequencies could be determined by analysis or simulation, or by direct noise-injection measurements. Both of these have the advantage of being available during product design and development, so that problems can be identified and solved early on, while design changes cost the least and timescales won't be as badly affected as discovering problems when immunity testing a product that is supposed to be ready for supply.

Instantaneous ∆Vs

EN 61000-4-14 uses a carefully defined way of changing from the initial mains voltage to the ∆V test level, using five single-cycle steps each of one-fifth ∆V, with each of these five steps only occurring during the final quarter of each single-cycle.

The author has no idea at all why such a complex method was used. EN 61000-4-11 (immunity to dips, dropouts and interruptions) simply applies the full voltage change at the zero crossings of the mains waveform, which is much simpler but still nothing like real life mains voltage changes. The causes of the voltage changes (e.g. the operation of an industrial welder) are not synchronised to the mains waveform, so in real life – mains voltage fluctuations will occur at any point along a mains waveform.

When testing with an abrupt change at a non-zero phase angle, a high-frequency transient is created. Both EN 61000-4-11 and EN 61000-4-14 seem to be designed to avoid creating such transients, even to the point of using unrealistic tests. Maybe the idea is that mains transients are best dealt with by testing using EN 61000-4-4, and having transients happening at the same time as voltage fluctuations or dips, dropouts or interruptions would just complicate matters and make it difficult to determine exactly what was wrong with a product that failed its test – was it the transient that caused the failure, or the voltage fluctuation?

But although not much work seems to have been done on immunity to simultaneous electromagnetic disturbances, [15] indicates that products that pass tests with individual disturbances can fail miserably when exposed to simultaneous disturbances at the tested levels. Of course, in the case of a real-life voltage fluctuation, the transient and the voltage fluctuation always occur simultaneously – so passing tests to both EN 61000-4-4 and EN 61000-4-14 might not be a good indication that real-life mains voltage fluctuations would not cause unacceptable interference.

Inductors suffer the greatest perturbations in magnetising currents when a.c. voltages are changed at their zero-crossing. Capacitors suffer the greatest perturbations in displacement current when a.c. voltage are changed at the peaks of their waveforms. So there may be no need to test with abrupt changes at a variety of phase angles – testing with changes at 0° and 180° might cover the worst-cases.

Three-phase products

When considering equipment that is connected directly to a PCC or IPC, it is reasonable to expect that voltage fluctuations in the three phase supply network will appear on all phases at once – due to the use of delta-star transformers to supply single-phase loads.

But EN 61000-4-14 applies its ∆Vs at the same phase angle on each phase, so there will be a small time displacement between the ∆Vs on each phase of a three-phase EUT. This does not represent real-life fluctuations, which will almost always occur on all three phases at the *same instant*, regardless of their phase angle at the time (this was also discussed in the section above).

So even if one of the phases experiences a ∆V that corresponds to the EN 61000-4-14 test method (unlikely, see earlier) the other two will experience ∆Vs that occur at phase angles that are ±120° different. So it might be more realistic to test three-phase products with simultaneous ∆Vs on all three phases. The programmable waveform synthesiser in the test generator should be as able to create such a simultaneous three-phase test just as easily as it creates the 'staggered three-phase ∆V' EN 61000-4-14 test.

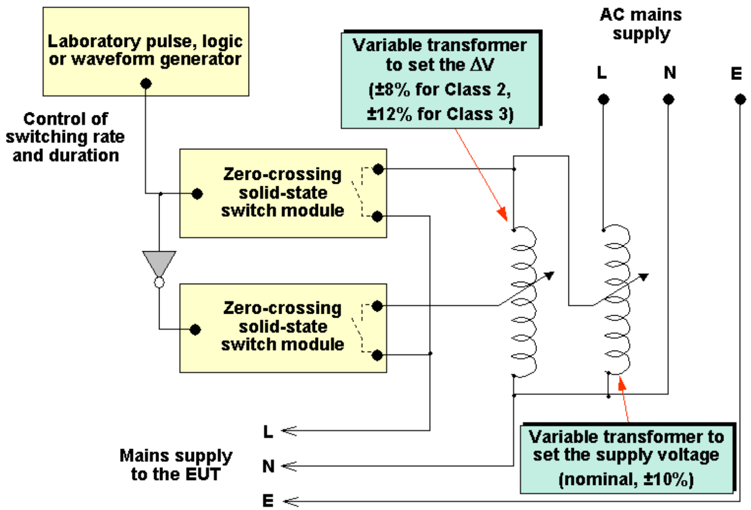
Testing using alternative test generators and/or different types of tests waveforms from those specified by EN 61000-4-14 may not be able to give 100% confidence that 'full-compliance' tests to EN 61000-4-14 would be passed. But such 'non-compliant' tests may actually be better than full testing to EN 61000-4-14 for improving the reliability or safety of a product – as discussed earlier – if they are better at simulating the actual mains voltage fluctuations that the product could be exposed to in real-life.

EMC Directive enforcement agencies generally assume that products 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 mains voltage fluctuation tests only involve low frequencies it is easy to develop low-cost alternative test generators that give useful results even though they don't comply with EN 61000-4-14. Such test generators could, for example, use triacs to switch between the outputs of two variable autotransformers, or between the secondary tappings on two fixed-ratio transformers.

Another technique might be to make standard audio frequency recordings of the typical (or worst-case) mains voltage fluctuations that products may be exposed to, even using an audio compact cassette recorder if necessary. (The audio signal must be taken from the mains via a safety-isolating step-down transformer that complies fully with the relevant part of EN 61558 for the mains voltage concerned. Care should be taken to ensure that the audio recording level is high enough that

Block diagram of a non-compliant low-cost voltage fluctuations tester



the added noise is insignificant – but not so high that it overdrives the recorder's input and distorts the waveforms even at the highest voltages.) These signals can then be played back through a suitably rated mains synthesiser or laboratory power amplifier (hired if necessary, *not* an audio amplifier even if its ratings seem adequate) to provide the mains power to the EUT.

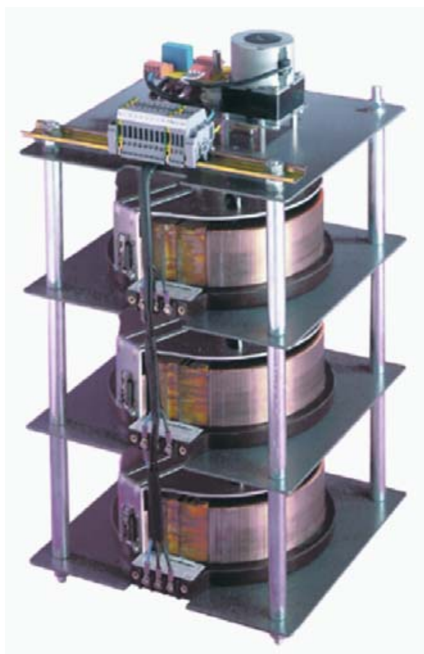
Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as 230V or 400V (3-phase) electricity. If you are not sure about all of these precautions – obtain and follow the guidance of a qualified and competent electrical health and safety at work person. When 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 other possibilities for alternative test generators and 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.

Example of a REO single phase variable transformer

Example of a REO automatically regulated and/or remotely controllable varirable transformer



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 61000-4-14 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 product is going into and there is no need to apply EN 61000-4-14 as well. This argument would probably be easier to win for a custom-designed (bespoke) industrial product intended for use at a specified site, than it would be for portable products or equipment that could be used in a number of locations or sites.

33 In-service failures and mains voltage fluctuations

If it is suspected that mains voltage fluctuations 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 power quality issues 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 voltage fluctuations, to try to correlate the likely EM disturbances with the failures that are occurring.

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

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

A problem with any automatic power quality monitoring equipment is that if it is not set up correctly, it 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.

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

Correlating alternative test methods with EN 61000-4-14

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 61000-4-14 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.

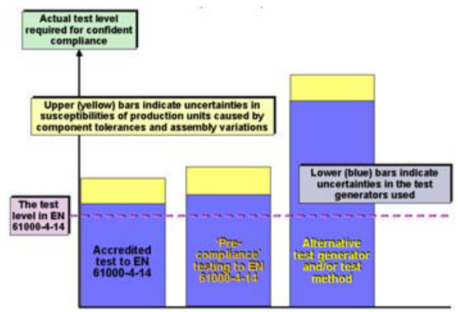
When alternative methods are used as part of a QA programme, or to check variants, upgrades, or small modifications, a 'golden product' is recommended to act as a sort of 'calibration' for the test equipment and test method. Golden product techniques allow low-cost EMC test gear and faster test methods to be used with much more confidence. Refer to section 1.9 of [16] 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 61000-4-14 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 products.

The closer a test method is to using the same tests and methodology as EN 61000-4-14, the more likely it is that a good correlation will be achieved. So (for example) testing with a test generator that uses triacs to switch between two variable transformers might only be able to be correlated with EN 61000-4-14 for a particular build state of a specific product. 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' 34

The need for engineering margins
(not to scale)



Even having EN 61000-4-14 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 a product, they are unlikely to use the same test laboratory or model of test generator as the manufacturer. So, an 'engineering margin' is recommended, because…

- There might be variations in the actual waveforms produced by different models of generators when testing the same product;
- 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 products 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 products, might make them more likely to pick up magnetically-coupled noise);

So, when testing an example product to EN 61000-4-14 in a fully compliant manner, it is recommended that additional tests with at least 20% higher levels of voltage fluctuations are performed, with the product still meeting its required functional performance specifications. This would mean, for example, that where EN 61000-4-14 specified a voltage fluctuation level of ±8%, the additional 'safety margin' test would apply at least ±9.6%.

At the time of writing it is understood that no product or generic standards listed under the EMC Directive call-up EN 61000-4-14 tests, so how (or if) a manufacturer tests for voltage fluctuations is entirely optional. But if EN 61000-4-14 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 61000-4-14 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 product.

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 product pass the alternative test method with the necessary engineering margins should be weighed against the cost of doing the testing properly.

[1] IEC 61000-4-14:1999, "*Electromagnetic Compatibility (EMC) – Part 4-14: Testing and measurement techniques Voltage fluctuation immunity test*".

[2] EN 61000-4-14:1999, "*Electromagnetic Compatibility (EMC) – Part 4-14: Testing and measurement techniques Voltage fluctuation immunity test*".

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

[4] EN 61000-4-30, *Testing and measurement techniques – Power quality measurement methods*

[5] European Union Directive 2004/108/EC on Electromagnetic Compatibility (2nd Edition), from: http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2004/l_390/l_39020041231 en00240037.pdf

[6] ITI (CBEMA) Curve and Application Note: http://www.itic.org/technical/iticurv.pdf

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

[8] 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.

[9] "*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.

[10] "*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.

[11] "*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.

[12] *"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.

[13] "*Banana Skin No. 303"*, EMC & Compliance Journal, January 2005, page 10, available from the "*Banana Skins compendium*", via http://www.compliance-club.com or at: http://www.compliance-club.com/archive1/Bananaskins.htm.

[14] *Banana Skin No. 104*, supplied by Nick Maroudas PhD, EMC+Compliance Journal, October 2000, see [13] for downloads.

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

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

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

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Keith Armstrong from Cherry Clough Consultants

This guide is one of a series. Email us at main@reo.co.uk if you would like to receive all of our mini guides and to be entered onto our mailing list

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

Contact: Keith Armstrong by email at keith.armstrong@cherryclough.com or visit the Cherry Clough website www.cherryclough.com

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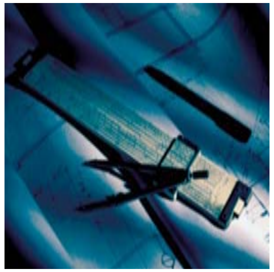

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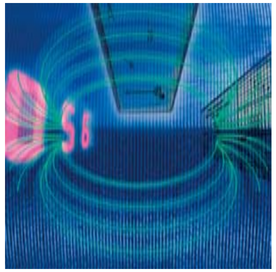

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