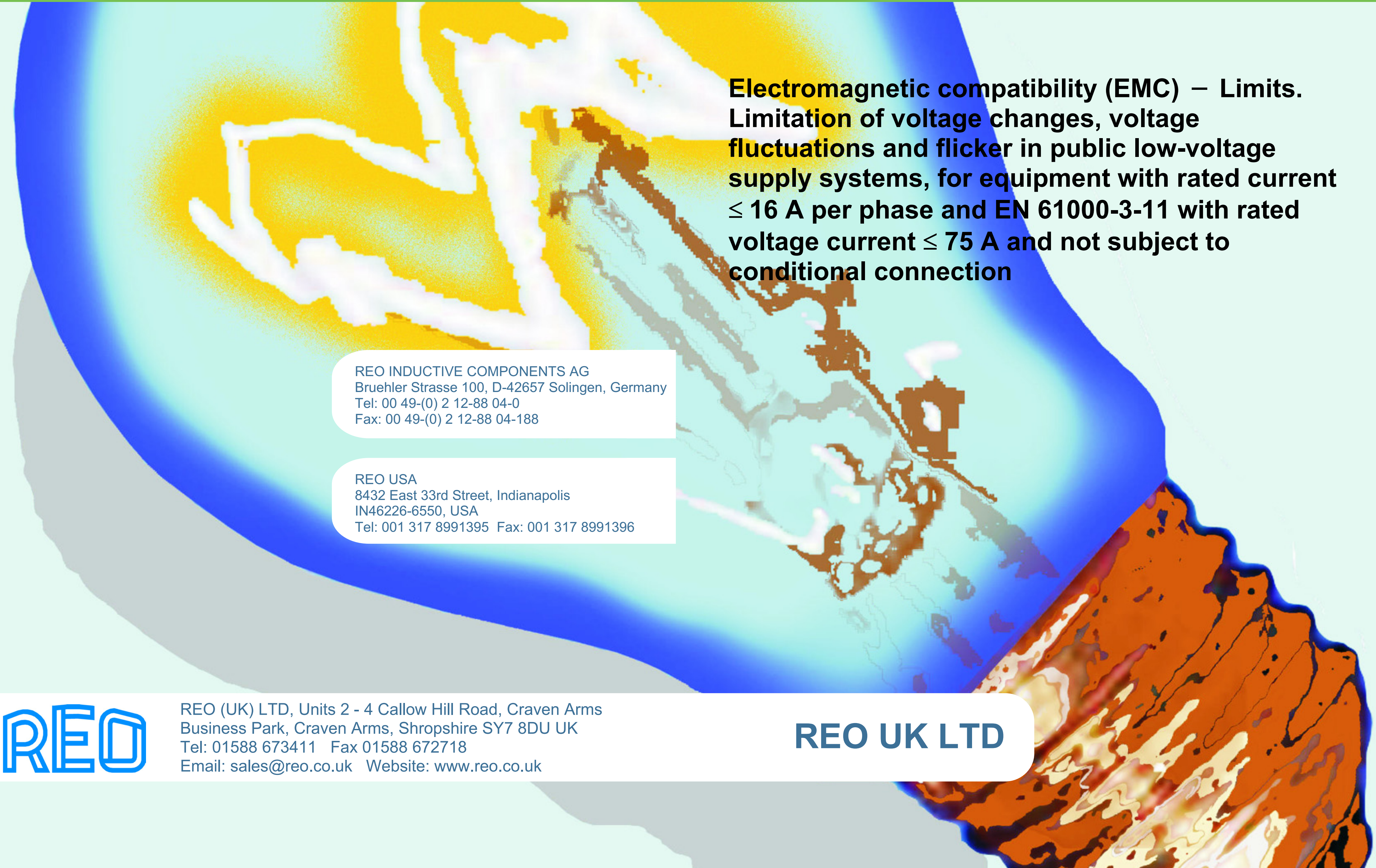
A Practical Guide for
EN 61000-3-3 and EN 61000-3-11



Electromagnetic compatibility (EMC) – Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and EN 61000-3-11 with rated voltage current ≤ 75 A and not subject to conditional connection

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Limiting an equipment's effect on its a.c. supply's voltage, and compliance with the EMC Directive

An electrical a.c. power distribution always has some impedance associated with it, so the current drawn from it by an item of equipment can cause its voltage to change, fluctuate or flicker. 'Flicker' is the term used for rapid voltage fluctuations, because they cause the intensity of the visible light from filament lamps, powered by the same supply, to flicker.

The basic standards that limit the effect that equipment can have on the public low voltage 50Hz a.c. power supply voltage, fluctuations and flicker are IEC 61000-3-3:1994 + Amendment 1:2001 for equipment up to 16A/phase that is not subject to conditional connection – and IEC 61000-3-11:2000 for equipment up to 75A/phase that *is* subject to conditional connection.

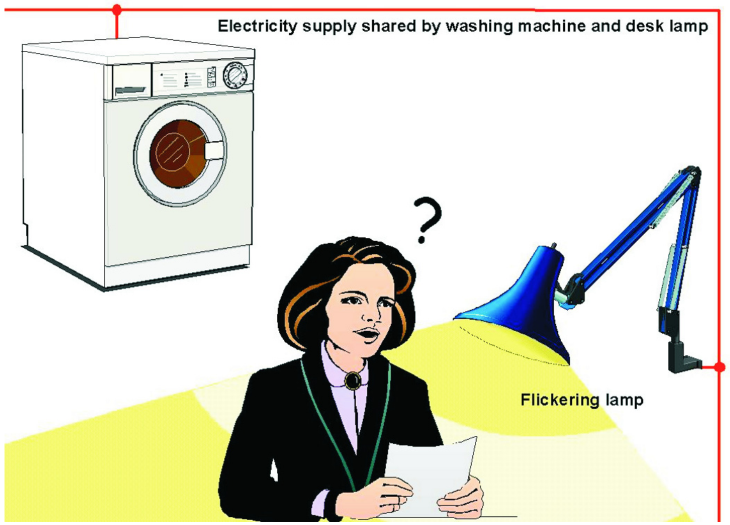
“Low voltage” (LV) refers to the 230/400V a.c. electrical power supply, often called the 'mains supply' in the UK.

“Conditional connection” means that the incoming a.c. power must meet specified requirements before it is permissible to connect a certain item of equipment to it.

Both of these standards have been adopted (with some 'common modifications') as the harmonised European standard EN 61000-3-3:1995 plus amendment A1:2001 [1], and as EN 61000-3-11:2001 [2] respectively.

Compliance with either EN 61000-3-3:1995+A1 or EN 61000-3-11 is now a requirement for all equipment within their scope, for conformity with the Electromagnetic Compatibility Directive (EMCD) [3] when using the 'self-declaration to standards' route to conformity (Article 10.1 in the EMCD).

Voltage fluctuations and flicker, example of a washing machine



Overview of EN 61000-3-3:1995 + A1:2001

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EN 61000-3-3 is a 'horizontal' EMC standard – which means that it applies regardless of the type of equipment or of any generic or product-family EMC standards which may also apply – and its scope covers all apparatus that is intended to be connected to the public LV supply (i.e. the public 230/400V a.c. supply) and which consumes up to 16A per phase.

The limits applied by this standard are based on the tolerance of the human vision system to fluctuations and flicker in the light output from a 60 Watt tungsten filament lamp.

EN 61000-3-3 has a few exclusions for which either the standard doesn't apply, or where the standard does apply but sets no limits, including…

- Equipment intended for use on a site which has its own dedicated distribution transformer and so enjoys a 'private LV supply' (a 'public' supply is one that is shared between more than one organisation or household).
- Equipment that consumes more than 16 Amps per phase (use EN 61000-3-11, see below).
- Equipment that operates at supply frequencies other than 50Hz.
- Equipment that is powered at supply voltages below 220 or above 250 V rms.

  (EN 61000-3-7 is available for optional use, and may become mandatory for equipment powered from a medium voltage (MV) or high voltage (HV) supply for compliance with the EMC Directive in a few years time).
- Emergency switching or emergency interruptions.

Equipment which does not comply with the limits in EN 61000-3-3 must be declared compliant with EN 61000-3-11 instead – and be subject to “conditional connection”.

The definition of “conditional connection” is: “*Connection of equipment which requires the users supply at the interface point to have an impedance lower than the reference impedance* Z_{ref} *in order that the equipment emissions comply with the standard”*. Clearly, however large the fluctuations in the current consumed by an equipment, if its supply impedance is low enough the current fluctuations will not cause voltage fluctuations or flicker on that supply to exceed the limits.

The reference supply impedance used in EN 61000-3-3 is chosen to be typical of LV supplies in Europe, so equipment which meets its limits may be connected to the public LV supply anywhere in the EU (sometimes called 'unfettered connection'). Equipment which requires a lower supply impedance so as not to cause lighting flicker is only permitted to be used where such low impedances exist (or are created specially for the equipment) – in other words, “conditional connection”.

Equipment which requires conditional connection must make this clear in its 'User Instructions', along with the specifications for its conditional connection (see below).

Overview of EN 61000-3-11:2001

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Like EN 61000-3-3, EN 61000-3-11 is a 'horizontal' EMC standard and applies to all apparatus within its scope that is intended to be connected to the public LV supply. Unlike EN61000-3-3, EN61000-3-11 covers equipment that consumes up to 75 amps per phase. EN 61000-3-11 has the same exclusions as EN 61000-3-3 (except for the 'more than 16A' exclusion, of course).

Equipment which complies with the requirements of EN 61000-3-3 – even if it consumes between 16 and 75 A per phase – is deemed to comply with both EN 61000-3-3 and EN 61000-3-11 and is *not* subject to conditional connection.

Equipment which does not comply with the requirements of EN 61000-3-3 must instead comply with the requirements of EN 61000-3-11 and be subject to conditional connection. Its User Instructions must specify that it is only intended for conditional connection, and specify the appropriate supply specifications.

There are two choices for specifying conditional connection in a manufacturer's User Instructions…

a) “Determine the maximum permissible system impedance Z_{max} at the interface point of the user's supply in accordance with section 6.2 of EN 61000-3-11, declare Z_{max} in the equipment's instruction manual and instruct the user to determine in consultation with the supply authority, if necessary, that the equipment is connected only to a supply of that impedance, or less.”

b) “Test the equipment in accordance with section 6.3 of EN 61000-3-11 and declare in the instruction manual that the equipment is intended for use only in premises having a service current capacity $\geq$100 A per phase, supplied from a distribution network having a nominal voltage of 400/230V, and instruct the user to determine in consultation with the supply authority, if necessary, that the service current capacity at the interface point is sufficient for the equipment.

The equipment shall clearly be marked as being suitable for use only in premises having a service current capacity equal to or greater than 100 A per phase.”

If a customer's a.c. power supply does not meet the requirements for the conditional connection of an item of equipment they have purchased, it will be illegal for them to connect the equipment to it. To avoid disappointing customers in this way, it is recommended that any limitations on the equipment's supply are made perfectly clear to potential customers before they commit to purchase.

When following the 'self declaration to standards route to conformity' (Article 10.1 in the EMCD) one or the other of these two standards must be applied to equipment which lies within their scopes. When following the 'Technical Construction File route to conformity' (Article 10.2 in the EMCD, usually called the TCF route) the Competent Body that assesses the draft TCF will most likely use these two standards as a guide to the appropriate areas of the EMC Protection Requirements and only permit relaxations from them where there is an appropriate and convincing technical argument.

When the second edition of the EMCD becomes mandatory sometime around 2006 and the TCF route disappears, along with the Competent Bodies, there will be no need for any third-party assessment of manufacturers' technical arguments for relaxing the requirements of EN 61000-3-3 or EN 61000-3-11. But there will then be a requirement that such technical arguments are documented and kept for ten years after the date of supply of the last item of equipment of that type, so they are available in case there is an official investigation.

Voltage fluctuations and flicker have been a problem for electrical power supplies (whether private or public) ever since the first public electricity supplies were created in the late 19th century. The UK's 'Lighting Clauses Act' of 1899 [4] was probably the first piece of EMC legislation in the world, and is briefly discussed later.

So it is recommended that – whether limits on voltage fluctuations and flicker are legally required or not – the voltage fluctuation and flicker emissions of your equipment is compared with what can be coped with by its intended a.c. supply without causing problems (taking its existing voltage fluctuations and flicker into account). It could turn out that even though there is no *legal* requirement – limitation of your equipment's emissions of voltage fluctuations or flicker might be a good idea for the customer's sake.

Note that where a product has a safety-related function, mere compliance with the EMC Directive is insufficient for ensuring that its 'EMC-related functional safety' is designed correctly – additional and/or tougher emissions and/or immunity requirements may be required. Refer to the IEE's guide [5] and the on-line article [6] for more on this topic.

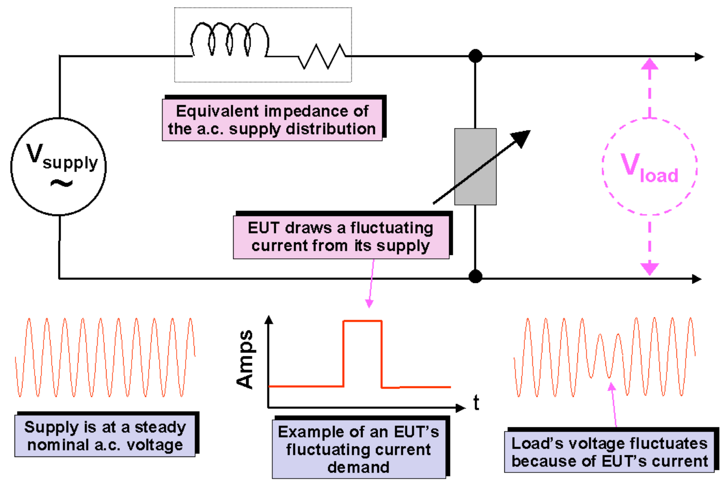
'Voltage fluctuations' are simply changes in the a.c. supply's rms voltage. 'Flicker' is defined as the “impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time”. Varying current loads on a power supply network result in voltage fluctuations due to the inevitable series impedances in the network. If these are of sufficient amplitude they can cause a typical human to perceive 'flicker' in the light output from lamps connected to the same a.c. supply.

Lighting flicker is a very old interference problem for both d.c. and a.c. electricity supplies that dates from the very first public electricity supplies in the 19th century. The very first item of EMC legislation ever – the UK's 'Lighting Clauses Act of 1899 [4] – was a precursor of EN 61000-3-3 and EN 61000-3-11.

The problem was that in 1899 filament lamps had not yet become reliable enough for the average consumer of electrical lighting products, and carbon-arc lamps were commonplace. During operation, the carbon electrodes burnt away so the arc had to cross an ever-wider gap. Eventually, the gap became so great that the arc became unstable and the current it drew from the electricity supply would fluctuate.

What passed for a public LV supply in the U.K in those days was mostly confined to Westminster, London, and a few other wealthy areas, and the supply impedance was not as low as we are used to these days. So the result of the fluctuating current in one arc lamp was to modulate the luminous intensity of all the other lamps connected to the same supply – causing them all to flicker annoyingly in time with the badly adjusted arc lamp. The 'Lighting Clauses Act' of 1899 therefore required arc lamp users to keep their electrode gaps adjusted at all times so that they did not cause flicker.

How voltage fluctuations and flicker occur



What problems are caused by voltage fluctuations and flicker?

Annoyance, stress, headaches, migraines, seizures

The original cause of legislation on voltage fluctuations and flicker was lighting flicker. For most people, lighting flicker causes annoyance and possibly mental strain. However, a significant proportion of humans are especially sensitive to lighting flicker and can suffer headaches, while a smaller proportion can suffer migraines and a smaller proportion still (but still significant, given the health implications) can suffer epileptic seizures.

Unreliability of distribution networks

On an LV supply that is loaded near to its maximum current rating, a momentary increase in load current can cause the current protection device to open, removing the power from numerous items of equipment and causing lost production, wasted time, and possibly increasing safety risks (e.g. when no other lighting, or only emergency lighting is available). The most likely cause of this problem is the surge of current that can occur when an item of equipment is first switched on its 'inrush current'.

We have all noticed that when switching on certain types of equipment, such as a cathode ray tube type monitor or TV, or a powerful hi-fi system or electric motor, any lights that are on may 'blink' momentarily. This is caused by the momentary dip in local supply voltage due to the large inrush currents into these types of equipment when they are switched on.

It has been known for the inrush current into equipment at switch-on to cause already heavily loaded fuses to open, even though they would have been able to support the total load current once the initial inrush was over. In one such case the switching on of a single spotlight caused a power failure that prevented an important announcement of the German Chancellor from being broadcast, at a huge cost penalty (millions of Deutschmarks) to the company that was contracted to provide all the live video and audio feeds to a number of TV and radio broadcasters.

So to help control this problem EN 61000-3-3 and EN 61000-3-11 include particular limits for the voltage fluctuations that are permitted during manual or automatic switch-on.

The supply distribution in the German Parliament building was probably not a 'public supply', so one could argue that even if EN 61000-3-3 and EN 61000-3-11 had been in force for some time, they would not have prevented the incident briefly described above. But the emissions standard for professional audio video and entertainment lighting equipment EN 55103-1 includes similar requirements and its scope is not restricted to public LV supplies.

Problem with restarting after a power supply interruption

This is another inrush current issue. During thunderstorms it can happen that the voltage on an overhead power line can rise excessively, and to protect equipment the line is automatically opened for a second or two to allow the overvoltage to dissipate. After this period the 'automatic recloser' operates and reconnects to the ine. Usually the line voltage is now within acceptable parameters and the supply continues, although sometimes the automatic opening and reclosing may need to happen a few times.

Equipment connected to an a.c. supply which depends on this overhead line suffers one or more supply interruptions, each lasting a second or two. The idea is that although such short interruptions are a nuisance, they are much preferable to the alternatives of long supply interruptions or equipment damage.

But when an a.c. supply is reconnected after a second or two's interruption, it has to provide all the switch-on inrush currents for all of its connected equipment at once – and this can overload the line's current protection and cause it to open. These current protection devices can only be reset manually, after the line has been checked for short-circuits, so an effect of high levels of inrush currents is to turn what would have been just a brief supply interruption into a supply interruption lasting several hours.

This is another reason for the inclusion of limits for manual or automatic switch-on in EN 61000-3-3 and EN 61000-3-11.

Sensitivity of electronic loads to dips in their a.c. supplies

Excessive voltage fluctuations (e.g. dips) in the a.c. supply which powers items of electronic equipment can cause them to suffer errors or malfunctions, due to their internal voltage 'rails' dropping momentarily below minimum levels.

There is an immunity test standard that covers this situation (IEC 61000-4-11) and there is a REO handbook that covers this. It obviously makes sense to try to limit the amplitude or rate of occurrence of such dips on a supply network, so that costly immunity measures are not required for most equipment, and this task falls to the voltage fluctuations and flicker emissions standards.

As before, it is usually the inrush currents at switch-on that cause the biggest problems, another reason for the inclusion of limits for manual or automatic switch-on in EN 61000-3-3 and EN 61000-3-11.

Full compliance testing to EN 61000-3-3

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This section of the handbook is based upon Chapter 3 of [7], updated as required to correspond to Amendment A1 to EN 61000-3-3:1995.

EN61000-3-3 regulates the degree to which a given item of equipment can cause voltage fluctuations capable of causing perceptible flicker. It does so by limiting the voltage variations that are generated across a reference load, and it places limits on three factors:

- The relative voltage change (maximum, d_{max}, and steady-state, d_c)
- The short-term flicker value P_{st}
- The long-term flicker value P_{lt}

These limits do not apply to emergency switching or interruptions, and the P_{st} and P_{lt} limits do not apply to manual switching or voltage fluctuations occurring less frequently than once per hour. But the voltage change limits d_{max} and d_c do apply to such occasional events, and this effectively places a limit on allowable switch-on inrush current for any apparatus, even where the switch-on is done manually.

Equipment that typically produces flicker in normal operation includes any device which switches varying loads during its operating cycle. Many household appliances fall into this category, and particular offenders are products which have heaters whose temperatures are controlled by burst firing, i.e. power is provided to the heater for a few cycles of the a.c. supply at a time, and the on/off ratio of the bursts controls the temperature. If the heating load is at all substantial this kind of equipment easily falls foul of the flicker limits.

It is a pity that simply replacing burst firing with its common alternative AC power control method – phase angle control – makes it likely to fail to meet EN 61000-3-2 (harmonic emissions into the supply) without suitable filtering.

Measuring instrumentation

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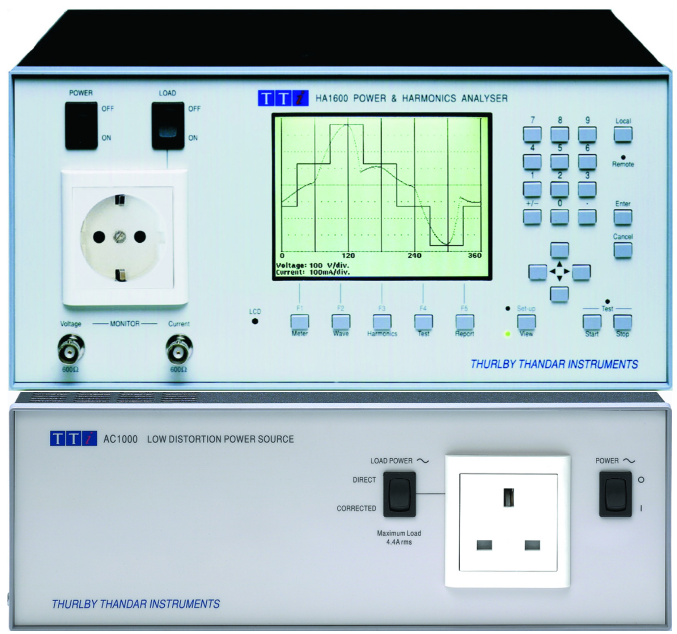
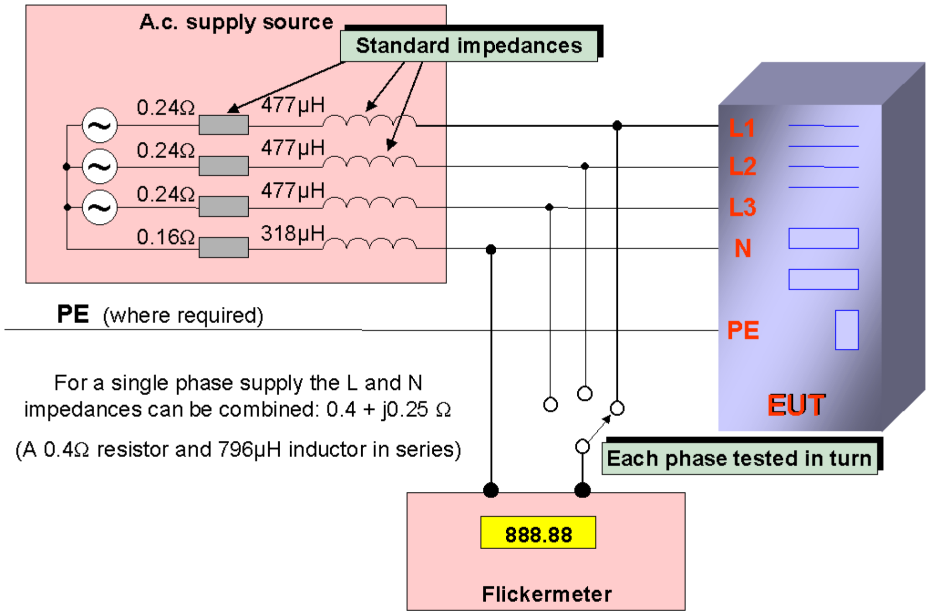
The basic instrumentation used to measure flicker has essentially the same block diagram and characteristics as the harmonics analyser used for testing the EN 61000-3-2 (see the REO handbook on this standard), and for this reason harmonics and flicker analysers are often packaged together.

But instead of measuring the current flowing in the supply, as is done for EN 61000-3-2, EN 61000-3-3 employs a defined source impedance and measures the voltage fluctuations at the a.c. supply terminals of the equipment under test (EUT). These voltage fluctuations are then analysed according to quite complex rules to compare them with the various limits.

A commercially-available combined harmonics and flicker analyser



The voltage fluctuations and flicker measurement circuit



The accuracy of this set-up is required to be such that the relative voltage change can be measured with a total accuracy of better than ±8% of the maximum allowed value. The measurement errors can be distributed between the reference impedance and the analyser as long as the total remains within this limit.

Before purchasing equipment for testing voltage fluctuations or flicker, always discover which version of the standard (and its amendments) you need to apply, plus the version of the basic flickermeter standard (see later), and ensure that the test equipment meets their requirements.

However, test equipment that does not comply with the specifications in the latest versions of the standards might be able to be made compliant with software upgrades from their manufacturers.

If the test equipment is not fully compliant it may still be acceptable if it is being used for development, 'pre-compliance' or QA purposes.

Relative voltage change waveform, d(t) and its derived quantities

The rms voltage is evaluated over successive half-periods (each 10ms) to build up a time-dependent view of the voltage fluctuations. The voltages are normalised to the nominal value of the a.c. supply to give a d(t) waveform, which is really a histogram, and two quantities are derived from it via a complex process involving the shape of the d(t) waveform…

- The relative steady-state voltage change d_c, which is the difference between two adjacent steady-state voltages separated by at least one change (steady-state is defined as persisting for at least 1 second);
- The maximum relative voltage change d_{max}, which is the difference between maximum and minimum values of the voltage change characteristics.

EN 61000-3-3:1995 +A1:2001 requires that d_c does not exceed 3%, d_{max} does not exceed 4%, and the value of d(t) during a voltage change does not exceed 3% for more than 200ms. Note that a d_c of 3% on a 230V supply implies an EUT supply current fluctuation of 14.6A.

Short-term flicker, P_{st}

The relative voltage changes d_c and d_{max} do not adequately characterise the flicker perceptibility by themselves. The human eye-brain combination varies in sensitivity to flicker as the flicker frequency changes. To account for this, the voltage fluctuations must themselves be processed over a period of a few minutes to take account of their frequency, the shape of the voltage change characteristic, and the cumulative irritating effect of repeated fluctuations.

In some special cases this processing of the d(t) waveform can be done analytically, according to the method given in section 4.2.3 of EN 61000-3-3.

But in general the d(t) waveform is passed to a "flickermeter", whose signal processing specifications are given in IEC 60868. IEC 60868 will eventually be replaced by EN 61000-4-15, and flickermeters that comply with either standard may be used for full compliance testing. The flickermeter applies a weighting to the d(t) waveform characteristic depending on its shape, and is the reference method for complying with EN 61000-3-3/A1.

The output of the flickermeter gives the short-term flicker indicator P_{st}. P_{st} is observed over a period of 10 minutes, to include that part of the operating cycle in which the EUT produces the least favourable sequence of voltage changes. P_{st} is not allowed to exceed a value of 1.

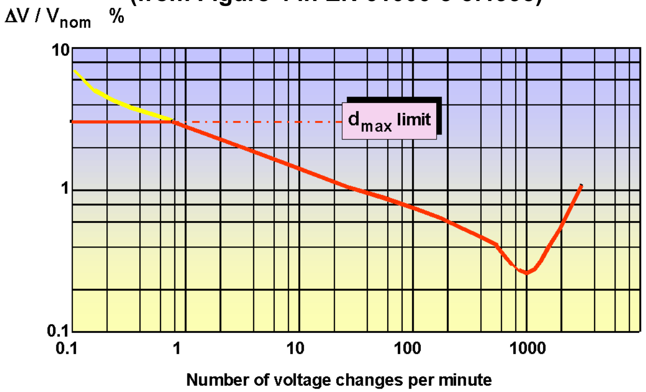
Where the d(t) waveform is known, P_{st} can alternatively be evaluated by computer simulation of a flickermeter. The simulation would need to incorporate the signal processing specifications of IEC 60868 [8] or EN 61000-4-15 [9].

For the special case of rectangular voltage fluctuations of the same amplitude separated by equal time intervals, the P_{st} value can be derived from Figure 4 in the standard. This shows the value of d(t) versus frequency which gives a P_{st} of 1, and illustrates the maximum physiological sensitivity to lighting flicker at around 1000 voltage fluctuations per minute (around 8Hz).

Long term flicker, P_{lt}

For equipment which may be operated for more than 30 minutes at a time, limits are also generally applied for its long-term flicker value P_{lt} – another parameter whose calculation is defined in IEC 60868 and EN 61000-4-15. P_{lt} is observed over a period of two hours and must not exceed 0.65.

Curve for P_{st} = 1 for rectangular equidistant voltage fluctuations (from Figure 4 in EN 61000-3-3:1995)



A typical REO load

Limits for manual switching & very infrequent voltage fluctuations

There are no P_{st} or P_{lt} limits applied for manual switching or voltage fluctuations that occur less than once per hour, and the limits for d_c, d_{max}, and d(t) are multiplied by 1.33.

This means that the EUT must not draw a switch-on inrush current of more than 25.9A – but don't forget that the flickermeter works in 10ms increments, so this value of 25.9A represents the maximum value of the *average current during the first 10ms after switch-on*. The peak current during that period can be much higher than 25.9A.

Most rectifier-capacitor input stages of a.c. - d.c. power converters will draw much higher currents whilst their capacitors are charging, but their peak current usually only lasts for a millisecond or two so the average current during the first 10ms period is significantly lower than their peak current.

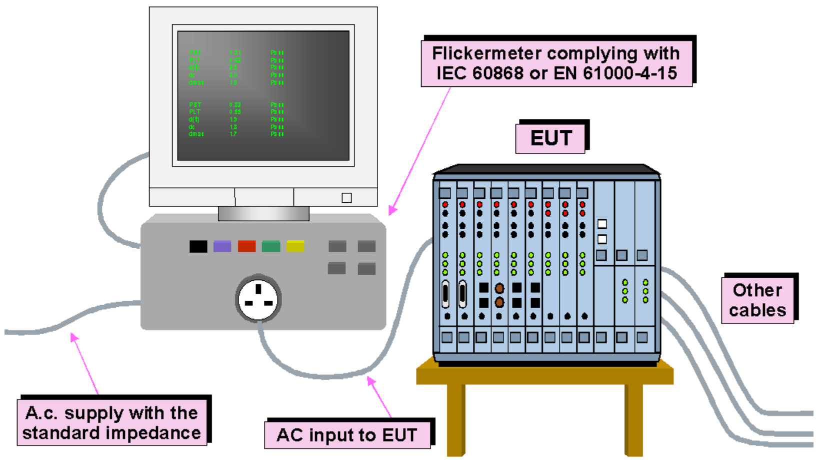
Test set-up and testing

Because there are no high frequencies involved, the test set-up is very simple. The flickermeter is powered from an a.c. supply source which has the standard impedances, and the EUT is plugged into the flickermeter. There are no requirements for ground reference planes, defined cable routes, etc.

Of course, the EUT must be set-up and operated as it will be in its normal operation. Where it drives any loads (electrical, pneumatic, hydraulic, mechanical, etc.) it is most important for this test that these are provided or simulated in a reasonably accurate manner.

Appendix A of EN 61000-3-3 specifies the method of operation and the test requirements for a variety of types of equipment, from cooker hotplates through lighting equipment to hairdryers and consumer electronics products.

A typical voltage fluctuation / flicker test set up



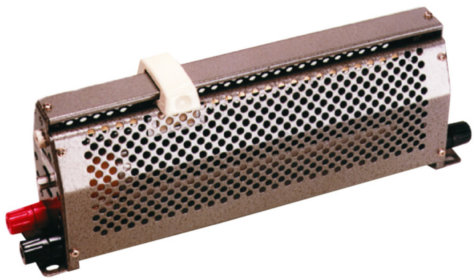
15 The requirements of the 230/400V a.c. supply used for testing

As well as having the specified source impedances, the a.c. supply must remain within 2% of the nominal value during the test and have a total harmonic distortion (THD) of less than 3%.

Because the impedance of the a.c. supply distribution in a building varies from location to location it will almost certainly not be the impedance required by EN 61000-3-3, and may also vary with the time of day (due to the addition or removal of heavy loads) – full compliance testing generally uses an isolated 230/400V a.c. source which has the specified impedances. This can be a synthesised source (such as the output of a continuous-conversion UPS), or the generator of a motor-generator set, with additional resistors and inductors added to create the correct phase and neutral impedances where needed.

The current capability of the 230/400V a.c. source is very important when measuring inrush currents, and many types of synthesised source might be current limited and unable to supply the current that the EUT would take from a real a.c. supply with the standard impedance. So when purchasing or designing an a.c. source it is best to ensure that it will source a short-term current which is at least 10 times larger than the EN 61000-3-3 or EN 61000-3-11 limits for inrush current.

REO chokes for correcting the supply impedance



REO variable tubular resistor

Full compliance testing to EN 61000-3-11

EN 61000-3-11 is a companion standard to EN 61000-3-3, and uses the same tested parameters and flickermeter. It allows equipment that consumes up to 75A per phase to be tested using the EN 61000-3-3 method and if it passes to be sold as suitable for unconditional connection.

16 Limits

The limits for the parameters tested by EN 61000-3-11 are not exactly the same as those in EN 61000-3-3. P_{st} and P_{lt} remain the same, but d(t) during a change must not exceed 3.3% for more than 500ms and d_c must not exceed 3.3%.

The d_{max} limit is 4%, but is allowed to exceed this under specified conditions. Equipment which uses manual switching, or automatic switching with a restart delay of “not less than a few tens of seconds”, or requires manual restart after an interruption in its a.c. supply is allowed a d_{max} of 6%. If such equipment is switched on no more than twice per day it is allowed a d_{max} of 7%. A 7% d_{max} is also allowed for equipment which is attended whilst in use, e.g. hairdryers, vacuum cleaners, some kitchen and garden equipment, portable tools, etc.

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Calculation of maximum system impedance for conditional connection

As was mentioned above, there are two ways of complying with EN 61000-3-11. The first is to use section 6.2 of the standard to calculate the a.c. supply system impedance that would be required for the equipment's current fluctuations to cause voltage fluctuations and flicker that met the limits. This calculation is based on knowing the values of the various tested parameters when tested with one system impedance, and then calculating the impedance that would be required to actually meet the limits.

When this route has been followed, the manufacturer must inform the user (via the User Instructions) of the maximum value of system impedance that the user may use when connecting the equipment concerned to the a.c. supply.

Testing that simulates a 100A service current capacity

The second way is to test the equipment just as is done for EN 61000-3-3 but with the lower a.c. supply system impedances typical of a connection to a service current capacity of at least 100A per phase. Two different impedances are specified, one for a single-phase equipment and one for three-phase.

The voltage fluctuations and flicker parameters that are measured during this test must not be more than the limits specified in EN 61000-3-11.

When this route has been followed, the manufacturer must inform the user (via the User Instructions) that the equipment must only be connected to the a.c. supply at places where the service current capacity is at least 100A per phase.

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Low-cost and/or non-compliant testing

Determining whether voltage fluctuations and flicker testing is needed at all

Very many types of products consume relatively steady power from the a.c. supply, and a few quick measurements and a few 'back-of-an-envelope' calculations can be enough to show that they would be certain to pass a voltage fluctuation or flicker test.

Many manufacturers need not bother with testing their products to EN 61000-3-3 or EN 61000-3-11 based on the results of calculations that they (or their test laboratory) performed which showed that they would cause negligible flicker. Of course, these calculations and their conclusions should be saved in an EMC technical file for at least 10 years after the date of last sale of the equipment type concerned, so as to be able to show due diligence in EMC compliance if challenged.

But equipment that consumes steady power and so does not cause voltage fluctuations or flicker during operation can still cause significant voltage fluctuations due to its inrush current at switch-on. Once again, a few simple measurements and calculations can show whether there is any point in testing this.

If switch-on testing is required after all, full compliance testing is quick and easy to do so should cost less than the full application of EN 61000-3-3 or EN 61000-3-11. Neither P_{st} or P_{lt} apply, so it is easier to use pre-compliance methods too.

Low-cost voltage fluctuations and flicker testing

It can be difficult to assess flicker without a flickermeter because of the complexity of the flickermeter specification, which is in turn due to the fact that flicker is a complex human physiological phenomenon.

However, if you decide to design your own flickermeter, consider that a combined harmonics and flicker instrument can be purchased for around £2,000 and gives compliant results (for equipment within the 1kW power rating of its 230/400V synthesised source). It will generally be a more effective use of time and money simply to buy such an instrument.

Section 4.2.3 of EN 61000-3-3 gives some guidelines to designers for estimating the effects of waveshape on peak voltage fluctuation for a few commonly-encountered shapes – but only for fluctuations that occur less than once per second. This makes it easier to estimate the likely voltage fluctuation emissions from an equipment calculation, simulation, or by simple measurements using standard laboratory equipment (oscilloscopes, for example). The accuracy of these estimates is claimed to be no better than ±10%, so results which are within 20% of a limit should be checked with a flickermeter on the actual equipment to ensure it complies.

If you are using a test supply with a total harmonic distortion of under 10% and a supply impedance as specified by EN 61000-3-3 you can measure the voltage fluctuation directly with an oscilloscope (using 'scope probes which comply with EN 61010 for use on 230/400V a.c. supplies, for safety reasons).

If instead you measure the load current fluctuation with another supply impedance you would need to transform it mathematically into the voltage fluctuation that could be expected using the standard impedance. But beware – the load current fluctuations will themselves depend upon the supply impedance, so if measuring the load current it is best to make sure your supply impedance is close (both in resistance and inductance values) to the standard supply impedance, or less.

Load currents can be measured using exactly the same sources and current transducers that were discussed in the REO handbook on EN 61000-3-2, and simply viewed on an oscilloscope. Once you know your equipment's load current waveshape – whether calculated, simulated, or measured with the standard source impedance or zero ohms – you can calculate or simulate the resulting voltage fluctuation waveshape. By referring to 4.2.3 and figures 5, 6 and 7 in EN 61000-3-3 you may find that you can predict the flicker emissions from your equipment.

If you have a circuit simulator running on your PC or workstation, you may be able to input the measured current into a circuit which is identical to the supply impedance specified by EN 61000-3-3, and discover the output voltage variations which result. Voltage fluctuations lasting less than 10 milliseconds are 'smoothed out' by the 10ms integration process required by EN 61000-3-3 and the flickermeter specification, and it may be possible to add a functional block to your simulator to give the corresponding output.

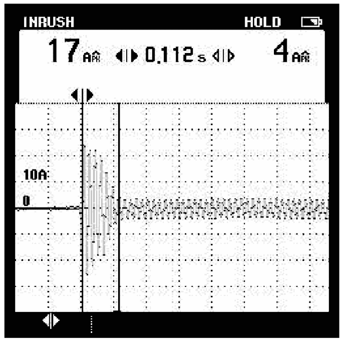
Low-cost inrush current testing

The switch-on inrush current limits in EN 61000-3-3 and EN 61000-3-11 are relatively easy to understand. It is also easy to use the current transducers as described in the REO handbook on EN 61000-3-2 with an oscilloscope to measure the switch-on inrush current waveform so as to provide the data needed to calculate its average value over the 10ms period employed by a flickermeter.

When measuring inrush current it is important to use an a.c. source that has approximately the correct impedance, and can source the peak current, otherwise the amplitude and waveshape will be different from what would be measured on a full compliance test.

A digitising (or analogue storage oscilloscope) is the best for recording the inrush currents or voltage fluctuations at switch-on, and their waveform data can be converted into a 10ms average figure using graphical “area under the curve” techniques. Some of the power quality instruments mentioned in the REO handbook on EN 61000-3-2 can operate as storage 'scopes with the appropriate probes to capture and display switch-on inrush current or voltage fluctuations.

Example of a switch-on inrush current (captured with a Fluke 43B and current probe)



Alternative a.c. sources

Of course, it is possible that your regular a.c. power supply is clean enough and has a reasonable enough impedance to use as a source for voltage fluctuation and flicker tests. You will probably find that the supply is the 'cleanest' and has the lowest source impedance in an industrial building which has its own distribution transformer, when no machinery or HVAC is running. Turning off the fluorescent lighting may also help clean up the waveform. If you are testing single-phase equipment, you may find that one of the phases in the building is 'cleaner' than the others – so use that.

In such an industrial building, it should be possible to find (or create) a.c. supply outlets that have the minimum length of distribution cable from the main distribution transformer. Such connection points will almost certainly have much lower resistance and inductance than the standard test impedances used by EN 61000-3-3 and EN 61000-3-11, and be relatively free from waveform distortion.

It is possible to use a known value of resistive load and an oscilloscope (or even a true rms voltmeter) to measure the resistive part of the impedance of an a.c. supply, and also to make an estimate of the inductive component. If the supply impedance is lower than that specified by the standards, resistors and/or inductors can be added in series so that tests are closer to full-compliance, making the results more accurate.

Measurements using an a.c. supply with non-compliant impedances, plus a few simple calculations, can provide useful information on whether a full compliance test would be likely to be passed with a wide margin, or whether design improvements are necessary (e.g. before having a full compliance test done). The formulae given in EN 61000-3-11 for converting fluctuation and flicker measurements into the values that would be expected with different supply impedances will probably be useful here.

Some people like to power their EMC tests via an isolating power transformer, to help reduce the low-frequency interference from the rest of their site. If conducted radio-frequencies (RF) are causing interference with the equipment under test, an isolating transformer will probably not provide enough attenuation and a filter will be needed. If radiated RF is causing interference problems, find another site or purchase a screened room (a shielding tent might be sufficient, and could cost less than a metal room).

REO isolating transformers

REO multistage filter for screened rooms

When using RF filters there are a number of other issues that will need to be taken into account to make them suppress the frequencies of concern effectively. Suitable filtering and shielding techniques are described in [11].

If working on exposed live equipment, an isolating transformer can be used to help reduce electric shock hazards – in this case, it is best to choose special 'high isolation' types with a very low value of primary-to-secondary capacitance.

It may be possible to use an isolating transformer that provides some harmonic suppression too, 'cleaning up' the a.c. supply waveform and helping to avoid the need for an expensive mains synthesiser.

REO modular system for interference suppression including RFI filter, harmonics filter and surge supressor

Motor-generator sets with electric motors can produce a 'clean' sine wave from a building's supply, or if the motor is a petrol or diesel engine it can of course generate a totally independent supply. Uninterruptible Power Supplies (UPSs) with low power ratings are almost commonplace but the only suitable ones for this purpose are 'continuous double-conversion' types, or other types run solely from batteries without a mains input. Second hand M-G sets or UPSs may be available at very reasonable prices.

Potentially serious problems with M-G sets or UPSs include the quality of their output waveform, their output impedance and peak current capacity (especially for the switch-on tests). Some M-G sets use crude electronic voltage regulators which result in poor quality output waveforms, and most M-G sets and UPSs have a relatively high output impedance (compared with the mains supply) which means that their output waveform can be more easily distorted by the non-linear current consumption of some EUTs, plus they may simply not be able to supply the full inrush current at switch-on, leading to an inaccurate test result. So you may need to use an M-G set or UPS with a rating that is much higher than the EUT's rated continuous power consumption, maybe even ten times more.

It is always a good idea to observe the supply voltage waveform with an oscilloscope and/or power quality analyser to check that it is a sine wave of adequate quality and that the current demand from the EUT is not causing unacceptable amounts 'flat-topping' or other waveform distortions. Note that it is quite hard to detect certain types of waveform distortions at levels of 3% or less simply by looking at an oscilloscope trace. Refer to the REO handbook on EN 61000-3-2 for more on measuring supply waveform distortion.

Lowest-possible-cost flicker testing

Precautions in low-cost and non-compliant testing

Connect the equipment concerned to an a.c. supply which is typical of its intended use, power a 60W tungsten filament light bulb from the same supply connection point (to each phase in turn, if it is three-phase equipment), then – with the 60W lamp being the sole source of illumination – operate the equipment and see whether the fluctuations and flicker from the bulb's light is significant or not.

This type of test is clearly not very accurate, although it can be improved by asking the opinion of other people (preferably those not involved with the equipment, e.g. a filing clerk). Reading a book or a letter (*not* a computer screen!) also helps assess lighting fluctuations and flicker, rather than staring at the bulb.

At the very least, this type of test can reveal which equipment operations, including switch-on, cause significant fluctuations or flicker, and there is no manufacturing company (however small) that could possibly claim that they can not afford to do a test like this.

Safety Note: Always take all safety precautions when working with hazardous voltages, such as 230V or 400V (3-phase) electricity. If you are not quite certain about all of these precautions – obtain and follow the guidance of an electrical "health and safety at work" expert. When constructing equipment that employs hazardous voltages, always fully apply the latest version of EN 61010-1 at least.

As always, using alternative testing methods or test equipment could give terribly inaccurate and misleading results unless a number of precautions are taken. It is essential to understand the relevant standards and their associated test equipment very well, and to understand how your methodology and test gear might influence the result.

It is almost always very important to follow the relevant standards as far as is possible. Even if the test gear is not the best, the test set-up and interpretation of results should follow the standard. The 'golden product' method described in section 1.9 of [10] can also be a great help in improving confidence in the results of low-cost tests, calculations, or computer simulations.

Golden product methods can even be used to 'calibrate' the lowest-possible-cost tests described above, for a certain individual.

On-site testing of voltage fluctuations, flicker, & inrush current

Testing three-phase equipment

There are no requirements in EN 61000-3-3 or EN 61000-3-11 to perform the tests on a special EMC test site, so tests can be carried out on-site as well as in a laboratory. But note that EN 61000-3-3 requires that the ambient temperature (whatever it is) remains constant during a test.

Both EN 61000-3-3 and EN 61000-3-11 require that three-phase equipment is tested one phase at a time.

[1] EN 61000-3-3:1995 + A1:2001 *"Electromagnetic compatibility (EMC) Part 3.3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16A and not subject to conditional connection."*

[2] EN 61000-3-11:2001 *"Electromagnetic compatibility (EMC) – Part 3.11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75A and subject to conditional connection."*

[3] European Union Directive 89/336/EEC (as amended) on Electromagnetic Compatibility. The Directives official EU homepage includes a downloadable version of the EMC Directive; 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; and progress on the 2nd Edition EMC Directive; all at: http://europa.eu.int/comm/enterprise/elec_equipment/emc/index.htm.

[4] *"Why the electricity industry needs to control the harmonic emissions and voltage changes associated with equipment rated less than 16A"* G.S.Finlay, EMCTLA Seminar concerning EN 61000-3-2 and EN 61000-3-3, 19th May 2000. www.emctla.org.

[5] 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.

[6] "EMC-related Functional Safety – An Update", Keith Armstrong, EMC & Compliance Journal, Iss. No. 44, January 2003, pp 24-30, on-line at: http://www.compliance-club.com/KeithArmstrongPortfolio

[7] *"EMC for Product Designers, 3rd Edition"* Tim Williams, Newnes 2001, ISBN 0-7506-4930-5.

[8] IEC 60868 *"Flickermeter – Functional and design specifications"*

[9] EN 61000-4-15 *"Flickermeter – Functional and design specifications. Basic EMC Publication"*

[10] *"EMC Testing – Part 1: Radiated emissions"*, Keith Armstrong and Tim Williams, EMC & Compliance Journal February 2001, pages 27-39, www.compliance-club.com/KeithArmstrongPortfolio.

[11] *"EMC for Systems and Installations – Part 4 – Filtering and shielding"*, Keith Armstrong, EMC & Compliance Journal, August 2000, pages 17-26, www.compliance-club.com/KeithArmstrongPortfolio.

EN and IEC standards may be purchased from 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.

Keith Armstrong of 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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