Chapter 9

Low frequency tests

The concept of EMC applies not only to high frequency phenomena. A product must be compatible with its electromagnetic environment, and there is no limitation on the frequency range encompassed by that environment, nor on the modes of coupling with it. A universal requirement is that the product should be compatible with its power supply; that is, it must be adequately immune from variations in the power supply, and it must not itself cause such variations. This is necessary whether the supply is DC, AC 50Hz mains or some other system-specific description, but for the public AC mains there are a number of common requirements which apply under the umbrella of the EMC Directive and which are discussed here.

9.1 Mains harmonic and flicker emission

Harmonic components of the AC supply input current to an item of equipment arise from non-linearities of the load over a single cycle of the input voltage. The EMC Directive includes requirements for measuring harmonic emissions as embodied in IEC 61000-3-2 (EN 61000-3-2), which covers all electrical and electronic equipment with an input current up to 16A per phase. This has a sister standard (actually a technical report), IEC 61000-3-4, for higher-powered equipment up to 75A, which has been supplemented by a full international standard, IEC 61000-3-12. The generation and control of mains harmonics are discussed further in section 11.4 and the standards themselves are surveyed in section 4.5.1.

Although the harmonic frequency range under consideration extends only up to 2kHz (the 40th harmonic of 50Hz), and therefore does not by any stretch of the imagination need to employ RF measurement techniques, there are many aspects of the measurement which are not entirely obvious and should be considered further. In the late 1990s the harmonics standard came under withering attack from several directions. There are three main interested parties: the supply authorities, who are keenly interested in preserving their networks from distortion; the manufacturers, who are equally keen to avoid expensive penalties resulting from harmonic limitation on their power supplies; and the test houses, who are keen to have a standard which will enable them to test accurately, completely and repeatably. The anomalies and gaps in the original 1995 edition of the standard allowed each of these parties ample opportunity for, to put it kindly, combative discussion. Several working groups later, a resolution was reached and the standard was drastically modified. This was first achieved in Europe by a CENELEC common modification and then the IEC document caught up, with the publication of its second edition in 2000. Since then there have been relatively few changes, apart from relaxing the limits slightly for Class A equipment under certain restricted conditions and adding test conditions for some further types of apparatus, and including modern refrigerators and freezers in Class D.

It should be appreciated that the requirements in IEC 61000-3-2 only apply to equipment powered from a 220–240V AC mains supply. There are no requirements, at least in this document, for harmonic limitation on equipment connected to lower voltage mains supplies, for instance for the US or Japanese markets.

9.1.1 Equipment

The original IEC 61000-3-2 defined the method of measurement, and each item of test equipment is specified. Figure 9.1 shows the basic measurement circuit, and its components are:

- an AC source;
- a current transducer;
- a wave analyser.

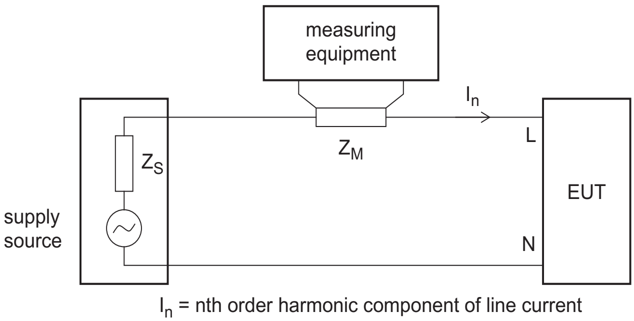


Figure 9.1 Mains harmonic emission measurement circuit

9.1.1.1 AC supply source

To make a harmonic measurement with the required accuracy you need a source with very low distortion, high voltage stability and settability and low impedance. In general the public mains supply will not be able to meet these requirements. IEC 61000-3-2 requires that the voltage must be stable to within ±2% of the selected level during the measurement, and the frequency within 0.5% of nominal. The odd harmonic distortion must be less than 0.9% at third harmonic, 0.4% at 5th, 0.3% at 7th, 0.2% at 9th and 0.1% at all others from 11 up; 0.2% is required for even orders from 2 to 10.

To meet these requirements typical test equipment uses a power amplifier driven by a 50Hz sinewave oscillator, with negative feedback to maintain the low output impedance. The output may be fed through a power transformer for voltage step-up purposes, but the transformer reactance must not be allowed to affect the output impedance at the higher harmonic frequencies. Variacs are not recommended for the same reason. The amplifier will need to be large to cope with the full range of loads – the standard covers equipment rated up to 16A, which is a power level of 3680W at 230V, although for in-house use your product range may not approach this level and a smaller amplifier would suffice. For high power and highly distorting loads the “model” AC source becomes quite difficult to realize. Including the maximum allowable transitory harmonics for Class B equipment, legitimate peak currents can be around 40A, although some equipment can substantially exceed this, and the source should be able to deliver this power level without distortion. If the measured harmonics are well over or under the limit then voltage distortion is a minor consideration, but it becomes important for borderline cases.

9.1.1.2 Current transducer

The current transducer couples the harmonic current I_n to the measuring instrument, and it can be either a current shunt or a current transformer. In both cases, the transducer impedance Z_M is added to the source output impedance and the two together must cause negligible variation in the load current harmonic structure. A shunt of less than 0.1Ω impedance and a time constant (L/R) less than 10µs is acceptable, but does not provide any isolation from the measuring circuit. A current transformer does offer isolation, but will need to be calibrated at each harmonic frequency and may suffer from saturation if the measured current includes a DC component or has a high crest factor.

9.1.1.3 Wave analyser

The wave analyser measures the amplitude of each harmonic component I_n for n = 2 to 40. According to the original standard it could be either a frequency domain type, using selective filters or a spectrum analyser, or a time domain type using digital computation to derive the discrete Fourier transform (DFT). Later editions of IEC 61000-3-2 have deleted any requirements in this standard and have redirected them instead to IEC 61000-4-7, which is a companion standard defining the reference instrument for harmonics measurement. The intention of this standard is to outlaw frequency domain instruments and only to allow DFT types. In practice, all commercial harmonic analysers are of this sort.

For steady-state harmonics different implementations of measuring instrument will give comparable results, but this isn't necessarily the case if the harmonic components fluctuate while the measurement is being made. The response at the indicating output should be that of a first order low-pass filter with a time constant of 1.5 seconds. IEC 61000-4-7 includes more specific details of the smoothing algorithm which performs this function on the discrete data values.

9.1.1.4 Pre-compliance measurements

A general test lab must be prepared for any kind of EUT and therefore has to invest in a test system which meets the specification over the whole range of likely EUTs. If you are doing pre-compliance tests in-house you may be able to use a system with a relaxed specification, which is therefore cheaper, especially if you don't expect to sail very close to the limits. We have already mentioned the use of a lower power amplifier as a supply source if you're not developing high-power products. You could use the mains supply directly if you are prepared to accept its inherent voltage instability and likely extra harmonic distortion, which could contribute a small amount extra to the measured harmonics. It is easy enough, with a resistive (lamp) load, to measure the actual voltage distortion at the time of test and make allowance for it in your margins to the limit.

As far as the analyser and current transducer are concerned, again a lesser accuracy may be acceptable if you increase the margin from the limits, and strict compliance with the IEC 61000-4-7 specification may be less important if your products don't produce time-varying harmonics.

A "simplified" method has been introduced in the fourth edition, for equipment that undergoes "minor changes or updates". This calls for verification that the product has an active input power within ±20% of the value originally tested, and that the THD of the supply current is less than 15%. This is allowed provided that in a previous full compliance test the harmonics were less than 60% of the applicable limits and the THD was less than 15%. No hint is given as to what might be regarded as "minor changes or updates".

9.1.2 Test conditions

Special test conditions for some types of equipment are given in IEC 61000-3-2, including TV receivers, audio amplifiers, VCRs, lighting equipment and various household appliances. Independent lamp dimmers and other phase-control devices should be set for a firing angle of 90°. Information technology equipment is tested with the equipment configured to its rated current. For all equipment, on manual or automatic starting or stopping, harmonic currents and power are not taken into account for the first 10 seconds after the switching event, so that start-up conditions are generally ignored.

The original 1995 standard required that all other equipment not covered by the specific conditions – that is, most equipment within the scope of the standard – should be operated by setting its user controls or program mode to give the maximum harmonic amplitude for each successive harmonic component in turn. If followed to the letter, this procedure would require an excessive amount of time and effort for a complete test. Later editions replace this with the altogether more reasonable requirement to conduct the test in the mode *expected* to produce the maximum total harmonic current under normal operating conditions. Power saving modes are to be disabled so that the equipment doesn't switch off during measurements.

A general requirement, though, is for repeatability: the repeatability of the measurements must be shown to be better than ±5%, for the same EUT under identical test and environmental conditions and with the same test system. This effectively means that you have to keep taking measurements for long enough to get a series of results that fall within this criterion. For EUTs with steady-state harmonics this means that the test can be quite fast, but it also means that with fluctuating harmonics you may be testing for a long time.

9.1.3 Equipment classification and limits

The original standard established four classes of equipment:

- Class B for portable tools;
- Class C for lighting equipment, including dimmers;
- Class D for equipment having the "special wave shape" of input current, and an active input power less than or equal to 600W;
- Class A for everything else, and particularly balanced three-phase equipment.

The "special wave shape" was defined by an envelope, effectively a means of distinguishing electronic power supply circuits, which normally draw their current for less than a third of the supply half-cycle. The harmonic limits are quoted as absolute values for Class A, whatever the input power, and as a set of sliding values proportional to input power for Class D. Figure 9.2 shows these limits graphically. For equipment with an input rating greater than 600W the Class A limits, being fixed, become proportionately more severe with increasing input power.

In recognition of the fact that low-powered equipment contributes little to the overall harmonic problem, there is a blanket exemption from the limits for equipment

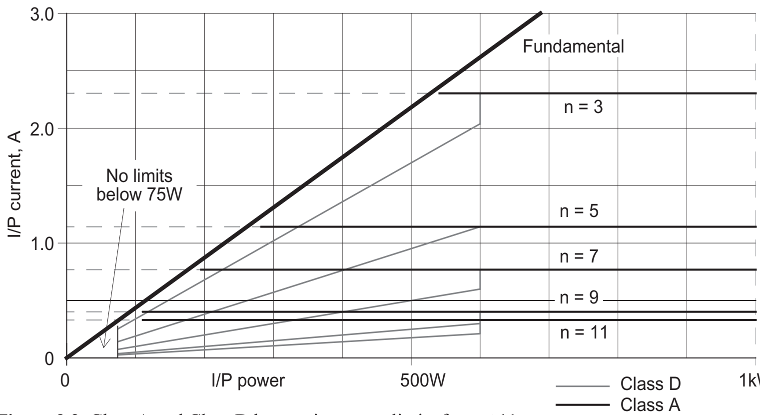


Figure 9.2 Class A and Class D harmonic current limits for n ≤ 11

with a rated power of 75W or less, other than lighting equipment; as there is also for symmetrically controlled heating elements with a rated power less than or equal to 200W and independent dimmers for incandescent lamps with a rated power less than or equal to 1kW.

9.1.3.1 Class D membership

The definition of Class D caused more problems for the standard than virtually any other aspect. If the EUT was suspected of being Class D, the test equipment had first to check the input waveform to confirm whether or not it fell inside the Class D definition, and then decide on its active power, before the limits could be applied. This led to a fundamental difficulty in deciding what current value to use, especially if the current and/or its harmonic content was fluctuating. This difficulty was decisively addressed in the CENELEC common modification, and in subsequent editions.

The working groups could not agree on an acceptable general method for applying the original Class D envelope. Since Class D is intended to constrain particular types of equipment which are considered to have the greatest impact on the power network, later editions have turned the definition on its head by specifying particular types of product to which the Class D limits must apply, and ditching the special wave shape. These are:

- personal computers and monitors
- TV receivers
- refrigerators and freezers with variable-speed drives

with a *specified* power (see next paragraph) less than or equal to 600W. All other equipment that is not Classes B or C is to be regarded as Class A, with some modifications from the original classification. The Class D envelope is effectively removed from the discussion. The equipment classification now stands as follows:

- Class B: portable tools and non-professional arc welding equipment;
- Class C: lighting equipment, excluding dimmers for incandescent lamps;
- Class D: personal computers and their monitors, television receivers, and refrigerators and freezers with VSDs;
- Class A: everything else.

Power basis for Class D limits

The Class D limits are given in mA per watt, and the basis for the power used for defining the limit value has been hard to pin down. In the later editions, *average* emissions are to be compared to limits based upon the *maximum* of the measured values of power in each observation time window over the entire duration of the test. The harmonic currents and active input power are measured under the same test conditions but need not be measured simultaneously.

In order not to arrive at a power at which limits change abruptly (for example, 600W or 75W), the manufacturer is allowed to specify a power level for establishing the limits, but this specified value must be within ±10% of the actual measured value. In other words, if the maximum measured power is close to the Class D cut-off point, the manufacturer has the option of specifying a power level within 10% of this value and therefore (potentially) of taking the apparatus outside the level at which severe limits apply. The purpose of this rather tortuous approach is to prevent the situation in which equipment operating near the boundary and tested under slightly different conditions might be subject to widely differing limits. The specified power for this purpose is not necessarily the same as the manufacturer's "rated" power for safety or functional purposes.

9.1.3.2 Professional equipment

A significant relaxation, present in the original standard, is that no limits apply (more correctly, limits are "not specified") for professional equipment with a total rated power of more than 1kW. Professional equipment is defined as "equipment for use in trades, professions or industries and which is not intended for sale to the general public. The designation shall be specified by the manufacturer". Later editions relax this slightly more, by allowing the connection to "certain types of low voltage supplies" of non-compliant professional equipment, if the instruction manual contains a requirement to ask the supply authority for permission to connect.

9.1.3.3 Other supply harmonic limits

There are few other standards which give explicit supply harmonic current limits, except the high-power counterpart to IEC 61000-3-2, which is IEC 61000-3-12 for currents between 16 and 75A. There is also IEC TS 61000-3-4, which is not a standard but a technical report and doesn't give limits. Requirements for 61000-3-12 rest on a parameter described as the "short-circuit ratio" R_{sce} of the equipment; for single phase equipment this is the ratio of the short-circuit power determined from the supply voltage and line impedance of the supply at the point of common coupling, divided by 3 times the equipment's rated apparent power. The manufacturer has to select a "presumed" value for R_{sce}, which clearly means that he must know the expected supply line impedance. Then the harmonic limits to be applied are chosen from various tables for different types of equipment. The higher the value of R_{sce} the more relaxed are the limits, but except for the lowest value of $R_{sce} = 33$, the user has to be instructed to determine, "in consultation with the distribution network operator if necessary", that the equipment is connected only to a supply of the required short-circuit power or more.

Supply harmonic currents for equipment for military use are subject to limitation, but not always explicitly. As well as various military standards relating to power quality, MIL-STD-461G CE101 tests conducted emissions on the supply lines, between 30Hz and 10kHz. Of course, any LF emissions will be controlled by this, not just supply harmonics. There are different requirements for aircraft and for naval applications. The trick to understanding it is to see that different limits apply for equipment rated above and below 1kVA: and it's counter-intuitive, in that more relaxed limits apply to the lower power rating. CE101 starts at the 60Hz fundamental and the harmonic limits are related to this value for equipment that takes more than 1A fundamental current, that is they become more relaxed for higher currents; but once your equipment takes more than 1kVA, suddenly the lower levels (adjusted upwards for actual fundamental current) kick in. For most electronic power supplies, this will mandate power factor correction, as described in section 11.4.2.2. Such a requirement is not unknown for commercial power supplies, and for ordinary mains IEC 61000-3-2 applies. But it doesn't apply to 115V or 440V 60Hz supplies; and neither does it apply a limit to professional equipment above 1kW. And as can be seen from Figure 9.3, the 61000-3-2 limits are higher than the CE101 1A ≤ 1kVA limits anyway. This can be a significant trip hazard for the military use of commercial power supplies (*cf* section 5.2.4).

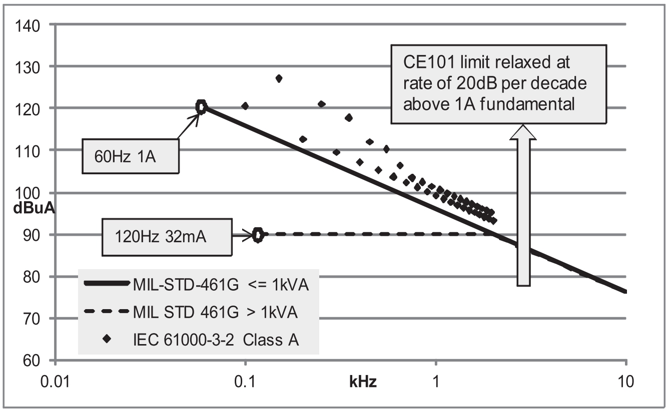


Figure 9.3 MIL-STD vs. IEC harmonic limits

9.1.4 Flicker

A companion requirement to IEC 61000-3-2 on harmonics is that provided by IEC 61000-3-3 on flicker. Flicker is defined as the "impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time". The problem with respect to EMC is that varying loads on a power supply network can result in voltage changes at common points of connection which are of sufficient amplitude to induce flicker in connected luminaires. The affected luminaires may have nothing to do with the load equipment that is causing the variations. Therefore, IEC 61000-3-3 – which applies to the same wide range of apparatus as does IEC 61000-3-2 – regulates the degree to which a given item of equipment can cause perceptible flicker. It does so by limiting the voltage variations that are generated across a reference impedance, and it places limits on three factors:

- the relative voltage change;
- 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. The voltage change limits do apply to manual switching, however, and this effectively places a limit on allowable switch-on inrush current for any apparatus. It has not been clear that this particular effect of the flicker standard was intended by its authoring committee. The standard also states that "tests need not be made on equipment which is unlikely to produce significant voltage fluctuations or flicker", and since the restriction on inrush current was not made explicit, this statement has been widely interpreted as meaning that most typical electronic apparatus whose steady-state load current changes only slightly can be excused testing. As a result, few manufacturers of equipment with electronic power supplies – many of which may well exceed the voltage change limit on switch-on – have been aware that they are in breach of the standard. Later versions of the standard do make it slightly clearer that inrush current limitation is intended, and do in fact change the limits in this context. But:

> For voltage changes caused by manual switching, equipment is deemed to comply without further testing if the maximum r.m.s. input current (including inrush current) evaluated over each 10ms half-period between zero-crossings does not exceed 20A, and the supply current after inrush is within a variation band of 1.5A (Clause 6.1)

Equipment that typically *will* produce flicker 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 mains 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, and is effectively outlawed.

Non-compliant equipment

IEC 61000-3-3 applies only to equipment with an input current up to 16A per phase used on 220–250V 50Hz power supplies, so is not relevant for products sold in countries with lower voltages. It refers non-compliant equipment to IEC 61000-3-11; this applies to equipment with a rated input current ≤75A per phase and subject to conditional connection. The EN versions of both standards are harmonized under the EMC Directive. "Conditional connection" means "connection of equipment which requires the user's 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 limits in this standard". The consequence of this for the equipment manufacturer and its user is either:

- the maximum allowable system impedance which will allow the equipment to meet the same flicker limits as in IEC 61000-3-3 is determined; the instruction manual then quotes this figure and instructs the user that the equipment should only be connected to a supply with this impedance or less, in consultation with the supply authority if necessary; or
- the manufacturer tests to show compliance against the same flicker limits with a lower reference impedance ($0.25 + j\ 0.25\Omega$ for a single phase supply), declares in the manual that the equipment is intended for use only in premises with a service current capacity ≥100A per phase, and instructs the user to determine that the service current capacity at the interface point is sufficient, in consultation with the supply authority if necessary.

9.1.4.1 Measuring instrumentation

The basic instrumentation used to measure flicker has essentially the same block diagram and characteristics as the harmonics analyser shown in Figure 9.1, and for this reason harmonics and flicker analysers are often packaged together. The difference can be seen in Figure 9.4, which gives the circuit for a three-phase supply, and which shows that the measured variable is now the voltage across the point of supply rather than the current drawn from it. The source impedance of the supply generator is more carefully defined so that load current changes in the EUT produce a defined voltage change, which is then analysed to compare it with the various limits. In fact, the standard itself

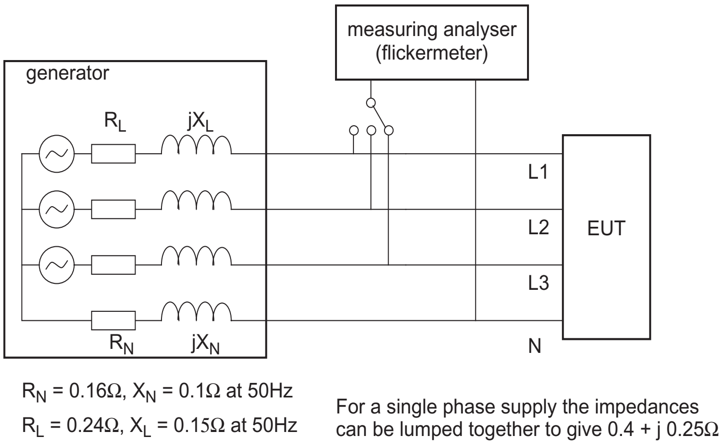


Figure 9.4 Flicker measurement circuit

allows either a direct voltage measurement or a current measurement, with the voltage calculated from the theoretical value of the source impedance. It is arguable that the latter is potentially more accurate, since there is less error introduced by departures from the ideal source impedance value, but virtually all commercial flicker measurement instruments use a direct voltage measurement.

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.

9.1.4.2 Relative voltage change

The RMS voltage is evaluated (typically by direct measurement, but it is also possible to calculate it given the active and reactive parts of the current waveform) over successive half-periods (each 10ms) to build up a time-dependent view of the voltage changes. The voltages are normalized to the nominal value to give d(t) and two characteristics are derived:

- 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.

The standard requires that d_c does not exceed 3.3% and d_{max} does not exceed 4%, and that the value of d(t) during a voltage change does not exceed 3.3% for more than 500ms. The value for d_{max} can be relaxed to 6% for manual switching and to 7% if the equipment is attended while in use, with some more complex relaxations for automatically switched equipment. To try and get some repeatability into measurements of switched inrush current, the standard requires 24 measurements, each taking into account the need to let inrush current limiting devices function properly, with the highest and lowest values subsequently deleted and the result being the average of the remaining 22.

Rough-and-ready calculation

If we ignore the reactive part of the load impedance and consider only the real value of 0.4Ω for single-phase supplies, and take the 4% d_{max} figure applied to a supply voltage of 230V, then the inrush current that will just touch that limit is

$$I_{inrush\text{-}max} = (0.04 \cdot 230)/0.4 = 23\text{A} \tag{9.1}$$

Clearly, if your known inrush current is nowhere near this figure, you need not be too concerned about compliance with this standard (see quote earlier). If it's approaching or greater, then you should do a proper measurement.

9.1.4.3 Short-term flicker

Voltage changes by themselves do not adequately characterize the flicker perceptibility. The human eye–brain combination varies in sensitivity to flicker as the flicker frequency changes. To account for this, the voltage changes must themselves be processed over a period of a few minutes to take account of the frequency of changes, the shape of the voltage change characteristic, and the cumulative irritating effect of repeated changes. Whilst in some special cases this can be done analytically, and in one case by direct comparison to a graph (see below), in general the voltage changes are passed to a "flickermeter", whose specifications are given in a separate standard, IEC 61000-4-15. The flickermeter applies a weighting to the voltage change characteristic depending on its waveform, and is the reference method.

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.

For the special case of rectangular voltage changes of the same amplitude separated by equal time intervals, the P_{st} value can be derived from a graph published in the standard and reproduced in Figure 9.5. This shows the value of d(t) versus frequency which gives a P_{st} of 1, and illustrates the maximum physiological sensitivity at around 8Hz or 1000 changes per minute.

9.1.4.4 Long-term flicker

In some cases flicker must be evaluated over a longer period, using successive values of P_{st} to give P_{lt}. The P_{st} values are averaged on a root-sum-of cubes basis according to equation (9.2).

The standard suggests that this is necessary for equipment which is normally operated for more than 30 minutes at a time. The observation period is 2 hours, that is, 12 successive P_{st} values are recorded. P_{lt} is not allowed to exceed a value of 0.65. The justification for this, in effect, is that whereas the average human can cope with a P_{st}

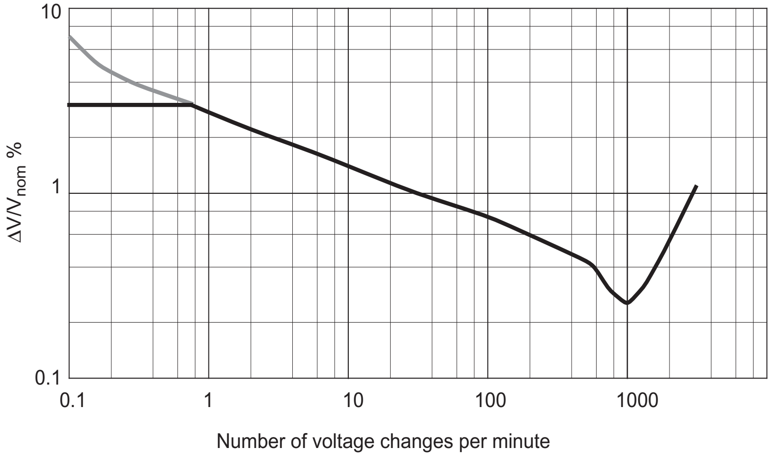


Figure 9.5 Curve for $P_{st} = 1$ for rectangular equidistant voltage changes

value of up to 1 for ten minutes, if the flicker continues for a longer time, the threshold of irritability lowers.

$$P_{lt} = \sqrt[3]{\left(\sum_{1}^{12} P_{st}^{3}\right) / 12} \qquad (9.2)$$

Annex A of the standard gives operating conditions and application of the limits for certain types of equipment, particularly white goods and consumer products. In several cases, P_{lt} does not need to be evaluated.

9.2 Magnetic field and power quality immunity

The two low frequency immunity tests that are most significant in the context of the EMC Directive are power frequency magnetic field, and voltage dips and interruptions on the power supply. Various other tests have or will become available as parts of IEC 61000-4, but there is a strong resistance to the widespread adoption of many more such tests by product committees for compliance purposes. On the other hand, for procurement purposes in specific industries such as defence there are a number of established low frequency tests.

9.2.1 Magnetic field

Testing with a steady magnetic field may apply to all types of equipment intended for public or industrial mains distribution networks or for electrical installations. Testing with a short duration magnetic field related to fault conditions requires higher test levels than those for steady-state conditions; the highest values apply mainly to equipment to be installed in exposed areas of electrical plants. (IEC 61000-2-7 gives values for various environments.)

Magnetic fields at power frequencies are common in the environment but are only a threat to certain types of equipment. Although the basic test method gives no especial advice as to which products should and should not be tested, all the generic and product standards, when they refer to the magnetic field test, state that it should be applied only to equipment "containing devices susceptible to magnetic fields". Experience suggests that this certainly applies to anything with a cathode ray tube – not that there are many of these left – and various other specialized components such as magnetic sensors. Audio apparatus that might be sensitive to hum pick-up should also be considered, but otherwise, general electronic circuitry can be assumed not to be relevant for this test.

9.2.1.1 IEC 61000-4-8

The test field waveform is sinusoidal at power frequency. In many cases (household areas, substations and power plant under normal conditions), the magnetic field produced by harmonics is negligible, but in special cases such as industrial areas with a concentration of large power convertors they can occur. Testing at present does not take them into account.

The magnetic field immunity test method is specified in IEC 61000-4-8. It requires the EUT to be immersed in a magnetic field of 50Hz or 60Hz sinusoidal (< 8% distortion) generated by an induction loop surrounding it, in three orthogonal orientations (Figure 9.6). Severity levels are defined as 1, 3, 10, 30 and 100A/m for continuous application, and 300 and 1000A/m for short duration (1–3 seconds) application.

The magnetic field is generated within the loop and the field uniformity is required to be 3dB within the volume occupied by the EUT. For various loop sizes, the maximum volume available is as follows:

- single square loop, 1m side: 0.6 x 0.6 x 0.5m high;
- double square loops, 1m side, 0.6m spaced: 0.6 x 0.6 x 1m high (0.8m spacing gives 1.2m height);
- single rectangular loop, 1 x 2.6m: 0.6 x 0.6 x 2m high.

The loop factor (H/I, magnetic field/current injected) is calibrated at the centre of the loop and allows a direct correlation between the current measured in series with the loop and the amplitude of the magnetic field that is produced. Although the standard describes particular designs of coil used with a ground reference plane, it does not forbid other designs provided that they meet the field homogeneity condition. For instance, multi-turn coils, which would allow a lower test current for a given field, would be acceptable. The requirements of the AC source and its output transformer turns ratio for use with a particular coil are given in Table 9.1 [85].

Table 9.1 Coil and source current and voltage for 1.5Ω, 19 mH, 65.73 A/m/A loop factor coil

H (A/m)	Coil		Transformer turns ratio N:1	AC source		
	I (A)	V (V)		I (A)	V (V)	VA
1	0.015	0.094	240	6.34×10^{-5}	22.5	0.001
3	0.046	0.281	240	1.90×10^{-4}	67.4	0.013
10	0.152	0.936	240	6.34×10^{-4}	224.7	0.142
30	0.456	2.809	8	0.057	22.5	1.282

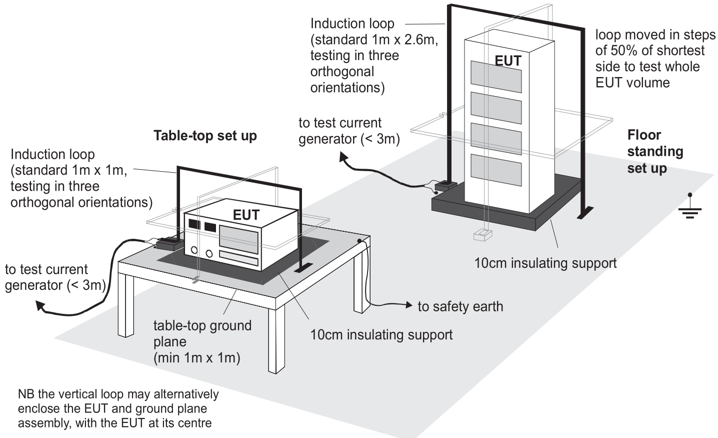


Figure 9.6 The magnetic field immunity test of IEC 61000-4-8

Table 9.1 Coil and source current and voltage for 1.5Ω, 19 mH, 65.73 A/m/A loop factor coil (contd.)

H (A/m)	Coil		Transformer turns ratio N:1	AC source		
	I (A)	V (V)		I (A)	V (V)	VA
100	1.521	9.363	8	0.190	74.9	14.245
300	4.564	28.090	8	0.571	224.7	128.21
1000	15.214	93.635	2.5	6.086	234.1	1424.53

9.2.1.2 Military magnetic field susceptibility

The military magnetic field susceptibility test of MIL-STD-461G RS101 or DEF STAN 59-411 DRS01 is quite different from any other radiated test (except for the complementary magnetic field emissions test, RE101 or DRE02, see page 153). The RS101 test is the converse of RE101, in that it applies a near magnetic field to the EUT, again over the frequency range 30 Hz to 100 kHz, to check its susceptibility. The standard method uses a radiating coil moved around the outside of the EUT to apply the magnetic field. This is a cumbersome procedure and easily prone to errors and non-repeatability. An alternative procedure is allowed (5.20.4) which uses Helmholtz coils to immerse the EUT in the field, but this limits the size of EUT that can be tested to what will fit in the space in between the coils.

The radiating coil is first calibrated with a second coil at a defined distance. The calibration is carried out at a fixed frequency of 1kHz and a fixed level of 110dBpT. Since the radiating coil is a passive device, unlikely to change its characteristics over time, it would be reasonable to perform this calibration procedure no more than once a year to confirm that the coil hasn't been damaged

The test is carried out according to the following procedure (MIL-STD-461G is quite prescriptive): first, select test frequencies that will be used for the final compliance test. Locate the radiating loop coil 5 cm from the EUT face or electrical interface connector being probed, with the plane of the loop parallel to the EUT faces and parallel to the axis of connectors. At any given frequency, generate magnetic field strengths at least 10 dB greater than the applicable limit but not to exceed 183 dBpT. This requires a software control of the signal generator output to match the limit curve.

Scan the applicable frequency range. If susceptibility is noted, select no less than three test frequencies per octave at those frequencies where the maximum indications of susceptibility are present. Reposition the loop successively to a location in each 30 by 30 cm area on each face of the EUT and at each electrical interface connector, and repeat this process to determine locations and frequencies of susceptibility, which should be recorded. From the total frequency data where susceptibility was noted, select three frequencies per octave over the applicable frequency range. (An octave is any frequency range of 2:1 top to bottom.) Note that the choice of the "three frequencies per octave" can be highly critical in the case of narrowband sensitivities.

Finally – this is the eventual compliance test – at each frequency determined as above, apply a current to the radiating loop that corresponds to the applicable limit (i.e. 10dB less than before). Move the loop to search for possible locations of susceptibility with particular attention given to the locations found earlier, while maintaining the loop 5 cm from the EUT surface or connector. Verify that susceptibility is not present.

9.2.2 Voltage dips and interrupts

There should be a defined and controlled response of the EUT to discontinuities in the mains supply. IEC 61000-4-11 defines immunity test methods for these phenomena.

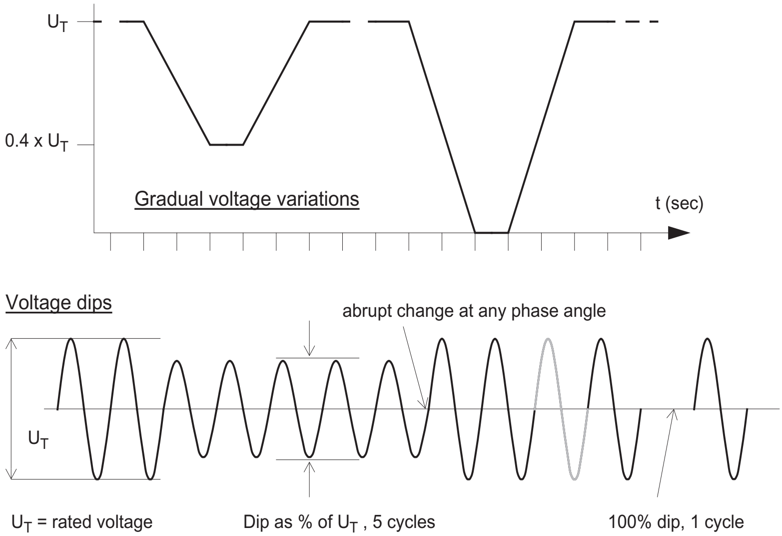
Electrical and electronic equipment may be affected by voltage dips, short interruptions or voltage variations of the power supply. Voltage dips and short interruptions are caused by faults in the network, in installations or by a sudden large change of load. In certain cases, multiple dips or interruptions may occur. Voltage variations are caused by the continuously varying loads connected to the network. These phenomena are random in nature and can be characterized in terms of their deviation from the rated voltage and their duration.

Voltage dips and short interruptions are not always abrupt. If large mains networks are disconnected the voltage will only decrease gradually due to the many rotating machines which are connected. For a short period, these will operate as generators sending power into the network. Some equipment is more sensitive to gradual variations in voltage than to abrupt change.

9.2.2.1 Applying voltage dips and interruptions

Different types of tests are specified in the standard to simulate the effects of abrupt change of voltage, and, optionally, a type test is specified also for gradual voltage change. Testing can be done either using electronically controlled switching between the outputs of two variacs or by controlling the output of a waveform generator fed through a power amplifier. The latter is more usual for low-to-medium power applications.

Tests are given for voltage dips and short interruptions (an interruption is a dip to 0% of the supply) and for short-period voltage variations. The preferred values for period and level of dips are listed in the table in Figure 9.7. Tests of dips and interruptions are significant as these are referenced in the generic immunity standards and many product standards. The generic standard requirements are for a half-cycle dip to 70% of rated voltage, a 5-cycle dip to 40% of rated voltage and a 5 second interruption. The performance criterion which applies to the latter two tests is that



Preferred test level % U_T	**Preferred duration # of cycles**
0 (interruption) 40 70	0.5, 1, 5, 10, 25, 50

Figure 9.7 Supply voltage dips and variations

temporary loss of function is allowed, provided that it is self recoverable or can be restored by operation of the controls; i.e. a latch-up or a blown fuse is unacceptable.

A significant part of the specification of the test generator is its ability to cope with the peak inrush current of the EUT without affecting the test result. If, for instance, the inrush current was high enough to pull down the source voltage significantly, the test might not show up an effect (such as a blown fuse) that could occur on a "stiffer" power supply. The maximum capability of the generator need not exceed 500A for 230V mains, or 250A for 110V mains. If the EUT draws significantly less than this, a generator with lesser capability is allowed provided that the EUT inrush current is less than 70% of the peak drive capability. But in this case you have to verify the generator's actual capability, and the standard gives a specific way of doing this, by driving the rectified output into a 1700µF capacitor. If you are using your laboratory's mains supply, via a variac-type dip generator, you may find that it can't meet the full specification because of the combined impedances of the mains supply and the variacs.

A further quirk of the test is the effect that a half-cycle dip can have on a product with an ordinary 50Hz mains transformer (as opposed to a direct-off-line switchmode supply). When only one polarity of the mains voltage is removed, the reapplication of the next half-cycle will drive the core of the transformer into saturation and create a very high inrush current, potentially 10 to 40 times the rated current, until the transformer recovers. Clearly the generator must be able to supply this current in the test, and it may have implications also for the design of the product's input circuit.