AC Sources for IEC 1000 Harmonics and Flicker Testing

APPLICATION NOTE #101

IEC 1000-3-2 and IEC 1000-3-3

The IEC 1000-3 standard is concerned with the quality of the utility line power. To ensure good power quality, this standard specifies limits for the distortion introduced by a load drawing non-sinusoidal or irregular current. Typical loads that exhibit this kind of behavior include office equipment, household appliances, or fluorescent lighting ballasts. Products that enter the European Economic Community have to meet these and other requirements and need a CE mark to show compliance.

Any form of active or electronic (i.e. non resistive) load will exhibit some distortion in the current waveform. A by-product of the introduction of more efficient power conversion designs is the distortion caused in the current waveform (Fig 1). Examples are switching power supplies, electronic ballasts for fluorescent lighting, and modern solid state motor speed controllers.

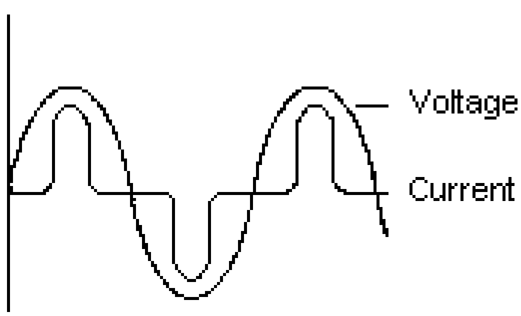

Figure 1 Typical input voltage and current waveforms for an uncorrected switching power supply

Effects of Current Harmonics

IEC 1000-3 has two parts that apply to AC powered loads. **IEC 1000-3-2** specifies the limit of load current harmonics that can be drawn from the utility. This is a measure of the distortion of the current waveform (Fig 2).

Generally, high current waveform distortion degrades the power factor of the load, causing wasteful heating effects in the supply cables and transmission lines. In three phase distribution networks this also causes high neutral current. Most neutral conductors in balanced three phase systems are not sized for significant current.

Another effect of significant current waveform distortion is caused because the utility supply has a finite impedance. The distorted current produces a voltage distortion due to the simple V=IR effect (Fig 3). This type of voltage distortion can in turn seriously affect other products powered from the same utility outlet.

A further problem is the effect of significant power

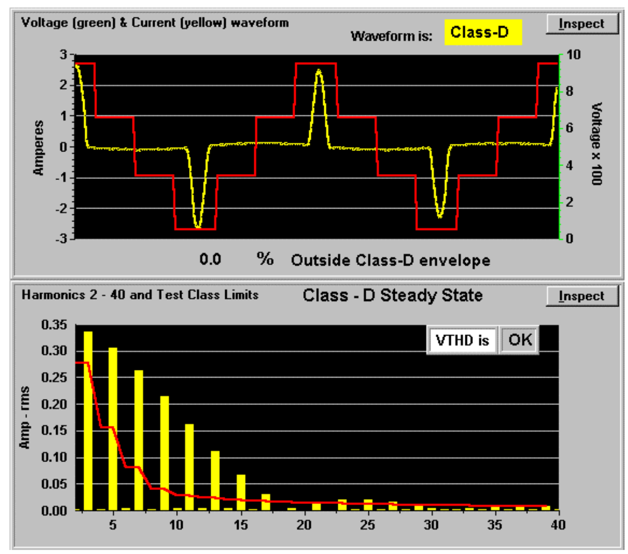

Figure 2 A time domain current waveform may also be represented in the frequency domain by harmonic analysis. In practice, odd harmonics dominate

being drawn at higher than fundamental frequency. For example, at a fundamental frequency of 50 Hz, products having high seventh harmonic load current will draw significant power at 350 Hz. This can cause major problems for devices such as power factor correction capacitors and transformers connected to the network. IEC 1000-3-2 specifies the limits of harmonic current either in absolute values or a percentage of the fundamental current for four distinct classes of electronic equipment.

Effects of Voltage Fluctuations or Flicker

IEC 1000-3-3 concerns short term changes in load current often caused by a thermostat controlled device switching a motor or capacitive load in and out; this in

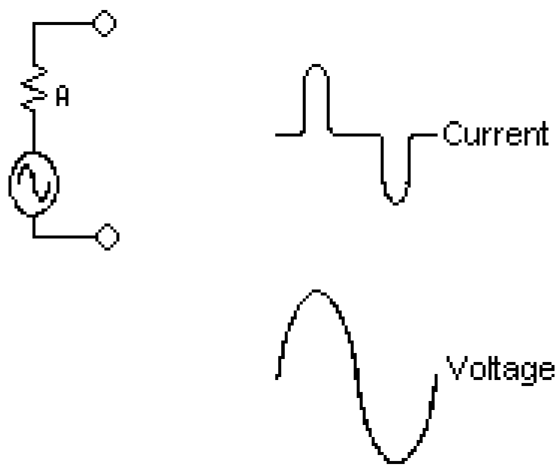

Figure 3 A supply with a finite source impedance Zo, will produce voltage distortion from a load drawing non-sinusoidal current. The degree of distortion depends on the load current and the source impedance.

turn can cause high in-rush currents. Such loads momentarily cause a change in the supply voltage due to a simple V=IR voltage drop (Fig 4), causing a lighting appliance connected to the same circuit to dim or, if the effect is repetitive, "flicker". Since the power of a lighting device is proportional to the square of the voltage, a 10% voltage drop causes a 20% reduction in light output.

IEC 1000-3-3 is often referred to as the flicker standard. The intent of 1000-3-3 is to prevent loads from causing annoying flicker effects from incandescent lamps connected to the same circuit.

AC SOURCES

IEC 1000-3 standards not only set limits for harmonic currents and voltage fluctuations, they also specify testing methods. The purpose of this application note is to explain which California instruments' AC sources are suitable to carry out tests to confirm compliance to these standards.

To perform tests to the IEC 1000-3 standards requires a stable 50 Hz power source producing a 230V rms output voltage. A source isolated from the utility line power has several advantages. First, it completely isolates the unit under test from any other form of load connected to the same circuit. Second, an even more obvious advantage, it allows precise control of the voltage and frequency; i.e. 50 Hz is not generally available in the USA and several other countries. To obtain 230V in the UK requires the use of a step down transformer.

The IEC 1000-3 standards concern single phase 230V, 16A rms supplies, and 400V L-L (230V, L-N) 16A rms per phase for 3-phase supplies. Standards are under consideration for single phase circuits above 16A rms. or above 16A rms. per phase for 3-phase circuits.

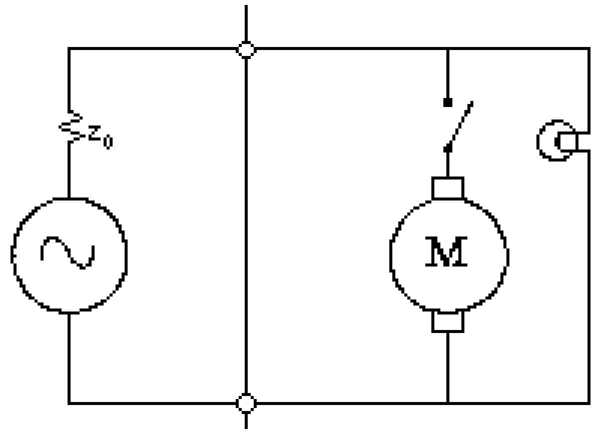

Figure 4 Depending on the source impedance Zo, and the inrush current of the motor, closing the thermostat switch will cause the output voltage to fall and the incandescent lamp to dim.

Since even very light loads are normally connected to 16A branch circuits, the standard applies to all loads less than 16A rms, or 16A rms per phase.

Other more esoteric parameters are specified for the power source such as; the test voltage must be maintained to within 2% of 230V (single phase), the frequency must be maintained to within 0.5%, the peak value of the test voltage must be between 1.40 and 1.42 times the rms value, and be reached between 87 to 93 degrees after the zero crossing. Also, for 3 phase supplies, the phase angle between each phase must be 120°, ±1.5°. All California Instruments AC supplies meet these generic parameters.

However, perhaps the most important specification parameter, and the most difficult to meet, concerns the distortion introduced on the output voltage waveform when the source is supplying non-sinusoidal current.

To gain an appreciation of the importance of this specification, consider first trying to measure the load current harmonics if the supply voltage has voltage harmonic distortion. Given a perfect, purely resistive load you will measure some current harmonics due to voltage harmonics. (Fig 5)

Now, consider a source with a finite output impedance; lets say 1 ohm. If the load draws a harmonic current of 1 amp at the third harmonic, then that will in turn produce a voltage distortion of 1 volt at the third harmonic. That voltage distortion is likely to "flat top" the voltage waveform, and reduce the total peak current. This will reduce the current harmonic distortion measured at the load, so that the user will not be able to determine whether the distortion caused by the load would pass the standard if the voltage waveform remained pure. (Fig 6) This is a potentially dangerous situation, because a load could pass when tested with an AC source with too high an output impedance, but fail in a real world situation.

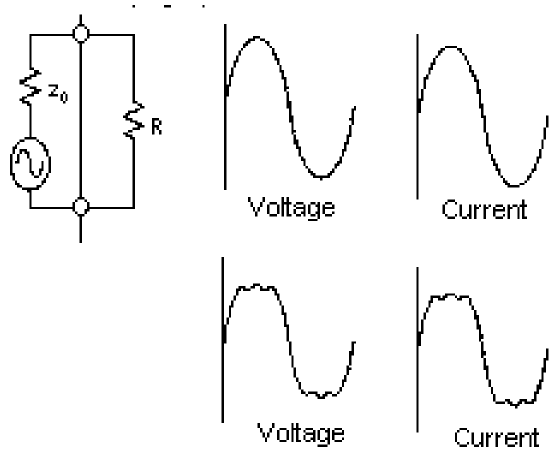

Figure 5 A purely resistive load will produce a current waveform identical to the voltage waveform.

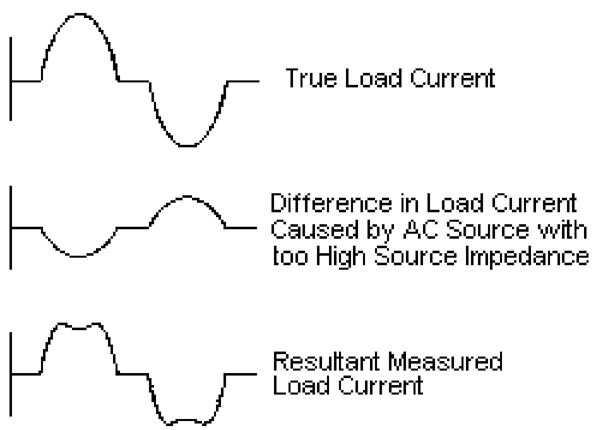

Figure 6 The combination of peak current from the load and output impedance of the source causes the voltage waveform to "flat top", reducing the peak current from that expected from an undistorted voltage source. This will give a false analysis of the load current.

Ideally, the source should have zero output impedance for IEC 1000-3-2 applications. However, this is difficult to obtain, especially with AC sources where the output is derived from more than one amplifier, as in a selectable single phase / 3 phase source. The different amplifiers, usually three, require a finite output impedance in order to detect the current flowing in each amplifier to load share correctly.

The IEC standard specifies the harmonic ratios of the test voltage, while the measurements are being made. This means that a worst case load, i.e. just on the limit of passing IEC 1000-3-2, must not introduce voltage distortion from the AC source greater than that specified below:

0.9% for harmonic order 3
0.4% for harmonic order 5
0.3% for harmonic order 7
0.2% for harmonic order 9
0.2% for even harmonics of order from 2 to 10
0.1% for harmonics order from 11 to 40

Since many loads easily comply with requirements of IEC 1000-3-2, it is often possible to use other AC sources, especially for higher power applications; e.g. California Instruments FCS18 (18kVA). To determine if the source is acceptable, power the load from the source and measure the voltage harmonic distortion. It must be less than the limits given above for the harmonic current measurements to be valid.

A suitable IEC test system such as California Instruments Compliance Test System will monitor AC source voltage distortion during the test cycle. This often allows low power AC sources such as the 1251RP to be used for testing low power products. This constitutes a very cost effective IEC test system that will notify the user if there is a distortion problem with the AC source. In this event, a higher power unit such as the 5001i may be required.

FLICKER REFERENCE IMPEDANCE

As indicated earlier, the IEC 1000-3-3 Voltage Fluctuations standard concerns changes in output current, producing changes in output voltage due to V=IR effects. To test for compliance with this standard, it is necessary that the AC source has a defined output impedance, specified as follows:

Phase Zo: 0.24 ohms + j 0.15 ohms, @ 50 Hz

Neutral Zo: 0.16 ohms + j 0.10 ohms, @ 50 Hz

We now have two conflicting output impedance specification requirements. IEC 1000-3-2 requires a very low output impedance, and IEC 1000-3-3 requires that the output impedance be a specified value, which is a complex impedance close to 0.47 Ω.

Two different methods to accomplish this output impedance are:

a) Use a matching impedance pad to “pad-out” the low impedance of the AC source. California Instruments produces a range of such Output Matching Network Impedances (OMNI) for many of its AC source product lines. (Fig 7)

b) Use a dynamically programmable output impedance. The California Instruments 5001iX is an example of an AC source that uses this approach, alleviating the need for an external OMNI option.

There is some controversy over which approach has more merit, as the IEC standard specifically calls out a lumped impedance network. Some users interpret this to mean that an electronically controlled impedance is not acceptable. Ironically, an electronically controlled impedance can be more accurate than a

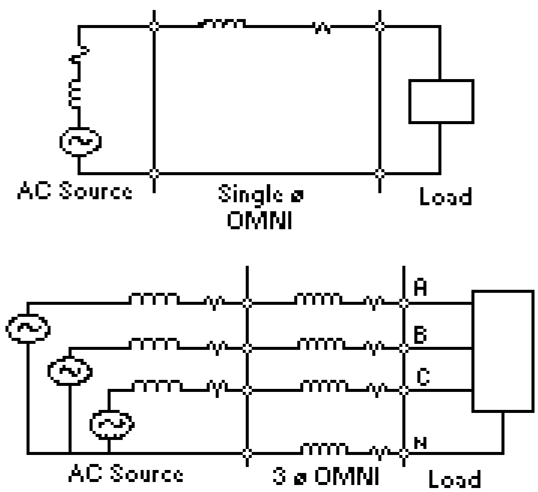

Figure 7 Single phase and three phase OMNI combinations.

lumped impedance. California Instruments has taken the position that either approach will not significantly affect the flicker measurement results and offers both alternatives to its customers.

SELECTING THE CORRECT AC POWER SOURCE

California Instruments offers the following AC power sources and power levels for IEC 1000-3 applications:

Models	Power range	Comments
P and RP	1,000 VA to 1,250 VA	For loads with up to 12 A peak currents.
L Series	750 VA to 18,000 VA	Requires OMNI option for Flicker
i Series	3,000 VA to 30,000 VA	also suitable for IEC 1000-4-11, IEC 1000-4-14 and IEC 1000-4-28. Requires OMNI-i option for Flicker
iX Series	3,000 VA to 30,000 VA	also suitable for IEC 1000-4-11, IEC 1000-4-14 and IEC 1000-4-28. Programmable impedance for Flicker

All models have been verified to meet AC source voltage distortion under worst case conditions.

In addition to these AC sources, California Instruments also offers complete IEC test systems that include the required harmonics and flicker measurement instrumentation.

The first step to selecting the most appropriate AC source is to determine whether the application is single phase, three phase, or could be either. Next determine the maximum power level required; remember that the standard covers up to 16A rms single phase, and 16A rms per phase, 3 phase. To cover all single phase requirements, the model 5001i is sufficient. It produces up to 18.5 Arms at 230 V which easily covers all single phase IEC test requirements.

For all 3 phase requirements, designate model 13500L-3XX-555. Both have associated OMNI configurations for IEC 1000-3-3 applications (XX refers to the controller option, -PT, or -HGA).

Many products (loads) to be tested do not require 16 A_{rms} (single phase or per phase). For lower power applications the model 1251RP offers 4.6 A_{rms} and model 2001L-1XX offers 6 A_{rms}, both single phase. For low power three phase applications, model 4500L-3XX-555 offers 6 A_{rms} per phase, 3 phase. These power sources may be suitable for lower power applications, depending on the class of equipment to be tested and the harmonic content of the load. Since classes A, B, and D specify the harmonic current limit in absolute terms, it is important that the expected harmonic currents are a factor of one-third of those specified in the standard for use of a 6A rms power source to be valid. (Class C is lighting equipment.)

Two options are available for applications involving both single phase and three phase testing. The 4500L-3XX-Mode-555 offers a choice of 16 A_{rms} single phase, and 6 A_{rms} per phase, 3 phase from a single source, whereas the 15003iX-MODE-iX offers 55.5 A_{rms} single phase, and 18.5 A_{rms} per phase, three phase. Follow the chart in Fig 8 (last page) to select the correct AC source for your application.

Single amplifier L Series sources, 2001L (single phase) and 4500L (for 3 phase applications) have a frequency range extending to 550 Hz. However, paralleled amplifier L Series sources (4500L for single phase applications and 13500L for all applications) are limited to a fundamental frequency operating range of 45 Hz to 67 Hz. All other product series support 16 Hz to 500 Hz frequency output and DC coupled outputs.

RMS AND PEAK CURRENT CONSIDERATIONS.

In practice it is noted that for IEC 1000-3-2 applications the AC source must be able to support a peak repetitive current of approximately 2.5 times the rms current; i.e. approx. 40A. If the load draws a significantly higher repetitive peak current, it is unlikely to pass IEC 1000-3-2.

For IEC 1000-3-3 the important specification parameter that can be used to determine the peak current requirement is A_{max}. This effectively specifies that after any change in load, the rms voltage of the first half cycle after that change must not be more than 4% below the rms value of the previous 10 cycles (Fig 9). Since we start with 230V, the delta voltage (dmax) caused by the change in load should not be more than 9.2V rms, or 13V peak.

Since we know that the complex source impedance is specified at 0.47 ohms for single phase circuits, this means that the additional current to produce the 13V peak drop cannot be more than 27.7A peak (from I=dv/Z, 13/0.47). The total peak current is therefore approximately (16A rms x 1.4)+27.7=50A pk.

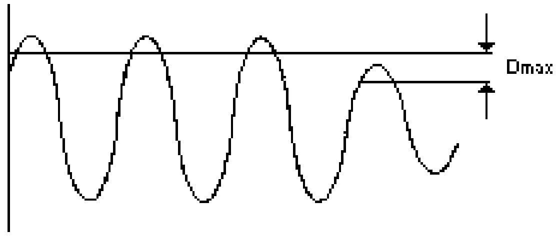

Figure 9 For most practical purposes, the value of d_{max} must not be greater than 4%. dmax is defined as the difference between the rms value of the first half cycle after a change in the load condition and the rms value of the previous 10 cycles, compared to the rms value of the previous 10 cycles.

Therefore, a source able to supply 230V, 50 Hz, 16A rms 50A pk. single phase, or per phase for three phase systems, will meet the testing requirements of IEC 1000-3.

For configurations with the MODE option, two OMNI matching pads are required, one for single phase applications, and the other for three phase applications.

OMNI ratings can be determined by the suffix numbers. The first one identifies the number of phases, the second the rms current rating per phase; i.e. OMNI-1-16 is single phase, 16A rms. The OMNI - 1-18i and OMNI-3-18i impedance matching networks should be used with the 5001i and 15003i respectively to meet IEC 1000-3-3 source impedance requirements. Refer to the i Series data sheet for more information.

Note:

IEC 555-2 = EN 60555-2 = IEC 1000-3-2
IEC 555-3 = EN 60555-3 = IEC 1000-3-3

CE Mark Sources

Customers that require CE Marked AC power sources should consider the i Series or iX Series of products. L Series AC sources are not CE Marked.

Turn Key IEC Test System

For single phase IEC conformance test applications, the California Instruments CTS system offers a complete source and measurement system solution. The CTS is a turn key IEC test solutions which includes an AC source, power analyzer and reference impedance. IEC Test software is included with each CTS system. Refer to the CTS Series data sheet for more information.

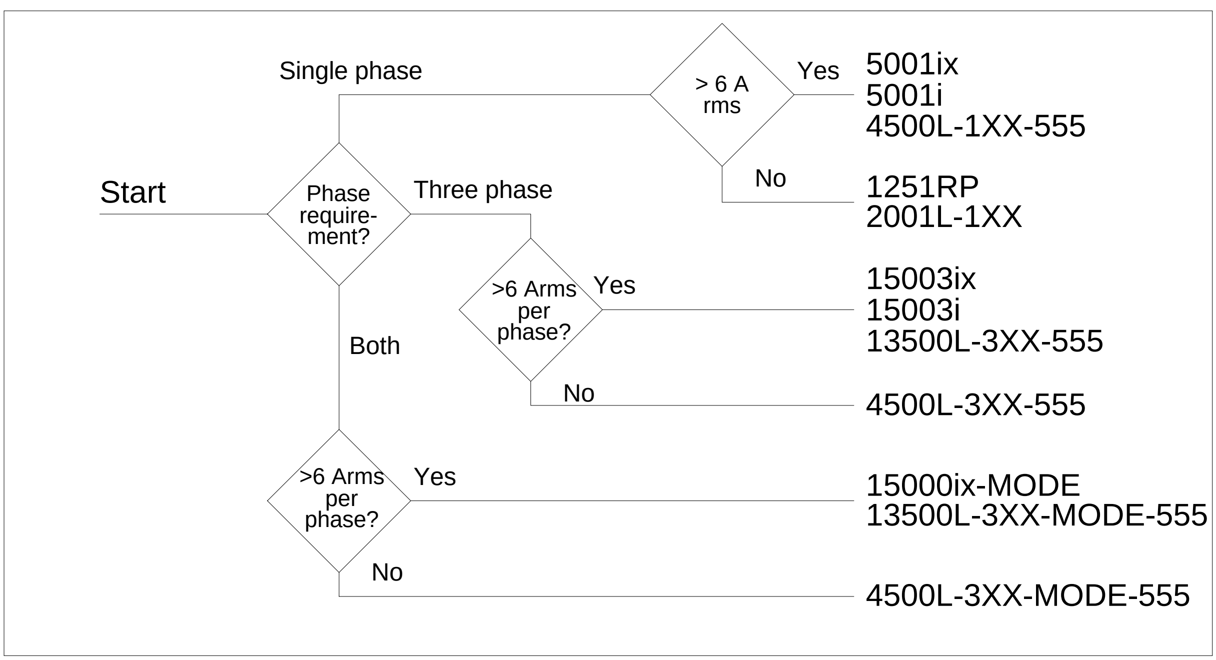

Figure 8 AC Source Selection Guide

HARMONIC LIMITS FOR IEC 1000-3-2

CLASS A*

Harmonic (n)	Max. Current
Odd	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
$15 \leq n \leq 39$	0.15 * 15/n
Even	
2	1.08
4	0.43
6	0.30
$8 \leq n \leq 40$	0.23 * 8/n

*For Class B, multiply by 1.5

CLASS C

Harmonic (n)	Max. Percentage of the input current at
2	2
3	30 * λ
5	10
7	7
9	5
$11 \leq n \leq 39$	3

λ is the circuit power factor

CLASS D

Harmonic (n)	Max. current per watt mA/W	Max current A
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
13 and on	extrapolate 3.85/n	see Class A

Equipment Classification:

Class A: Balanced three phase, and all other equipment not included in B through D
Class B: Portable tools
Class C: Lighting equipment (including dimmers)
Class D: Equipment $P \leq 600W$ with special input current wave shape, if not included in A through C. (Many low power products with switching power supplies, e.g. PC's, printers and fax machines fall into this category.)

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