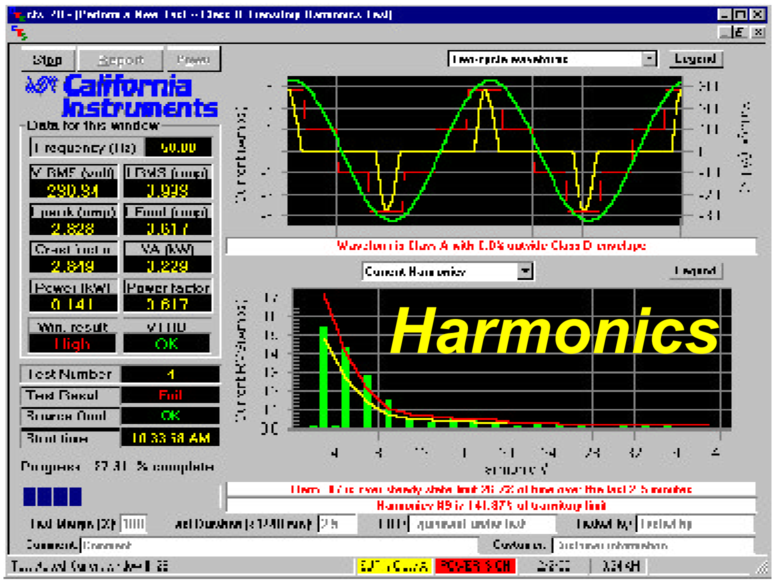
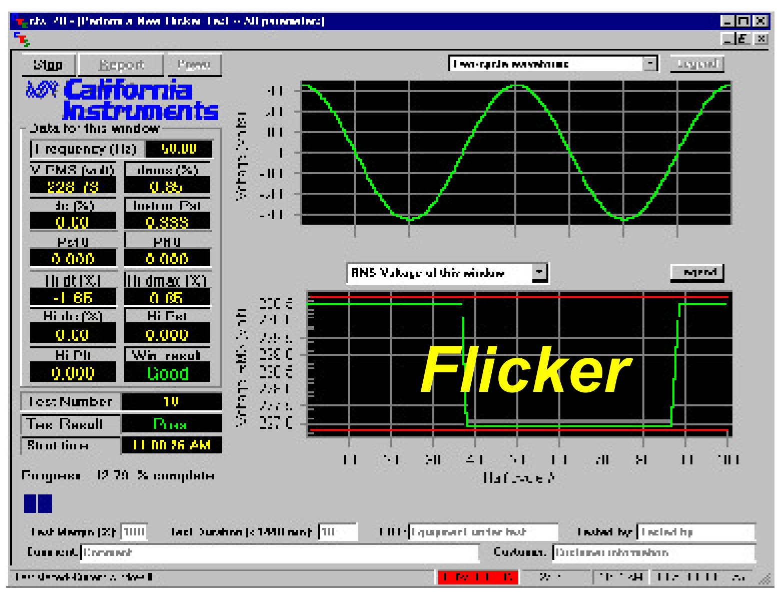
Application Note 119B

California Instruments CTS series Compliance Verification Tutorial





California Instruments

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Introduction

This tutorial provides a basic understanding and background for EN 61000-3-2 (harmonics) and EN 61000-3-3 Flicker (Voltage Fluctuations) testing with the California Instruments Compliance Test System (CTS) series. Intimate knowledge of either IEC standard is not required to understand this application note, as it reviews key requirements of these standards, and the tests to verify compliance with these requirements. The European Union (EU) requires electrical products to pass a series of compliance tests, including harmonics, immunity and in some cases Flicker testing. This application note discusses the studies that resulted in the creation of the EN 61000-3-2 Harmonics - including the recently published Amendment 14 - and the EN 61000-3-3 Flicker standard - including Amendment 1.

This document also contains a description of the IEC-725 Reference Impedance and its purpose for Flicker testing. This lumped Reference Impedance, called OMNI, is available from California Instruments in both single and three phase versions. The single phase version can be integrated into the CTS hardware (option "-LR1"). Furthermore, the 5001iX power source offers programmable output impedance which can be set to the IEC-725 reference impedance values, or to the Impedance values required in Japan. There is an ongoing debate regarding the suitability of programmable (or synthetic) impedances for harmonics and Flicker testing. California Instruments conducted some comparative Flicker tests with the programmable 5001iX and with the OMNI (actual IEC-725 impedance consisting of resistors and inductors). This test data will be reviewed briefly, along with methods to verify performance of the CTS hardware and software.

Next, some cost considerations for EN 61000-3-2/3 testing will be discussed. Product development engineers and EMC professionals are concerned with escalating compliance testing cost, and the potential delays in product release. The California Instruments Compliance Test System (CTS) series represents a breakthrough in terms of technology and system cost. In addition, the power source of the CTS can be used for AC and DC immunity testing and multiple other jobs in engineering, and the test software has general applicability in power supply development efforts. A brief overview covering the various CTS configurations will be presented, which in turn allows the user to select the appropriate version and determine whether or not in-house (pre) compliance testing is cost effective.

The CTS' suitability for harmonics analysis in 100 - 120 Vac (60 Hz) applications, such as found in Japan and the US, will also briefly be discussed. Since the CTS is a PC based system and generates test reports using MS Word, creating documents such as this application note is greatly facilitated and illustrates the system's value in power (supply) engineering tasks.

Finally, the implications of new standards for higher power harmonics and flicker testing up to 75 A RMS per phase per EN/IEC 61000-3-11 and EN/IEC 61000-3-12 are discussed in Appendix B.

The reader may request a copy of the CTS 3.0 demo CD-ROM from California Instruments. The CTS software supports a test file replay mode, which permits the user to view both harmonics and flicker tests as if they are performed in real time. The demo disks contain actual test data files, thus permitting the user to "operate the system" on a PC without having the actual measurement hardware in place.

Power Quality and Standards

In the last two decades, the quality of electrical power has decreased in various industrialized nations. This is primarily due to the increased use of electronic equipment with so called nonlinear loads. These nonlinear loads cause harmonic currents, which in turn result in voltage distortion and subsequently cause other equipment to fail or malfunction. Complaints from customers experiencing light flicker as a result of voltage fluctuations go back even further than the harmonics problems. Big arc welding equipment and industrial presses caused consumers in Britain to complain to their utilities. Arc furnaces caused irritation in Germany, Japan and the UK. In Belgium, a lighting system of a dance hall caused voltage fluctuations that in turn caused light flicker in private homes. As a result, the Union for International Electroheat (UIE) came up with guidelines for maximum allowable flicker levels. These, and other concerns about power quality, eventually found their way into national and international standards.

IEEE-Std-519 , IEC555, EN61000-3-2/3 standards and Amendment 14

In the USA, the IEEE-Std-519 was first released in 1981, and the 1992 revision is widely used as a guide to control harmonics in electrical power systems. This standard covers recommended practices and requirements for harmonic control in electrical power systems, and mainly addresses harmonics, although Flicker issues are discussed as well. The International Electrotechnical Commission (IEC) released standards dealing with low voltage public supply system quality as well. The first edition of IEC 555-2 (harmonics) dates back to 1982, and IEC555-3 (voltage fluctuations or Flicker) came shortly thereafter. Subsequently, these two standards were revised multiple times, and finally released in the early 1990’s as IEC 1000-3-2 (harmonics), and IEC 1000-3-3 (Flicker). The latest revision of the Harmonics standard is EN 61000-3-2 Am14 effective Jan 1, 2001. The latest revision of the Flicker standard is EN 61000-3-3 Am1 and is effective as of November , 2000. The Flicker standards are based on a UIE/IEC report which found its way into a standard document called IEC 868, which in turn was approved as Euronorm EN 60868-0 by CENELEC on December 9, 1992. Most electrical apparatus sold within the member countries of the European Union (EU) have to meet the requirements of these IEC standards, as governed by the EMC directive.

The EMC Directive

IEC standards, although of worldwide importance, do not have the legal force of law unless accompanied by some national standard. In Europe, the EU issued the Electro Magnetic Compatibility (EMC) directive in order to unify rules and regulations in the member states. In the context of the EMC directive, the EU requires member countries to issue identical National Standards after CENELEC (Commité Europeén de Normalisation Electrotechnique) approves a European Standard. CENELEC membership includes the EU, Switzerland, Finland, and Iceland. Note that the EMC directive is much broader than just Harmonics and Flicker, and covers all electrical emissions and susceptibility aspects. Standards specify how much radiated and conducted electromagnetic emissions a product may cause. Other standards govern immunity i.e. a product’s susceptibility to the radiated and conducted emissions from other electrical devices.

For harmonics and Flicker, the relevant European standards are derived from the IEC 61000-3-2/3 versions, and are numbered EN 61000-3-2 (superseding EN 60555.2) and EN 61000-3-3 (superseding EN 60555.3). The individual member countries of the EU are required to issue identical national standards within 2 years after the European standard is formally published/announced in the official European Journal. Note that Europe is also in the process of unifying the electrical power systems of all countries to 230 Vac - 50 Hz. The IEC standards therefore primarily concentrated on 230 Vac - 50 Hz, and provisions for other line voltages and frequencies are under consideration.

Japan has adopted a national standard which differs from the IEC 61000-3-2/3 documents, as their power distribution differs significantly from the European system. While compliance with this harmonics standard is not mandatory, there is strict cooperation between industry, government and the utilities to make sure all new products placed on the market comply with the Japanse version of EN 61000-3-2. The CTS System supports testing to this standard as well.

Even though the IEEE-Std-519 provides some guidance, it is likely that the US will also adopt modified versions of EN 61000-3-2/3 in the future. Some efforts were already made to harmonize Amendment 14 of the EN 61000-3-2 standard with a possible new IEEE harmonics standard. In particular the common 200 msec acquisition window for evaluation of current harmonics for both 50 Hz and 60 Hz products will contribute to this harmonization.

The impact of poor power quality

The IEC standards in question deal with single and three phase electrical equipment having a current level of < 16 Amp rms. Most 230 Vac - 50 Hz household electrical equipment, test and measuring instruments, information technology products, consumer electronics, and lighting products, consume well below 16 Amperes. Thus the EN 61000-3-2/3 standards cover all these products. Because so many of these products utilize switching power supplies, they have a tendency to induce harmonics in the power distribution system. This can cause overheating in neutral lines, and can also be very detrimental to transformers and motors. To understand the negative impact of harmonics, the example of a simple 17 inch VGA monitor can be used.

Figure 1

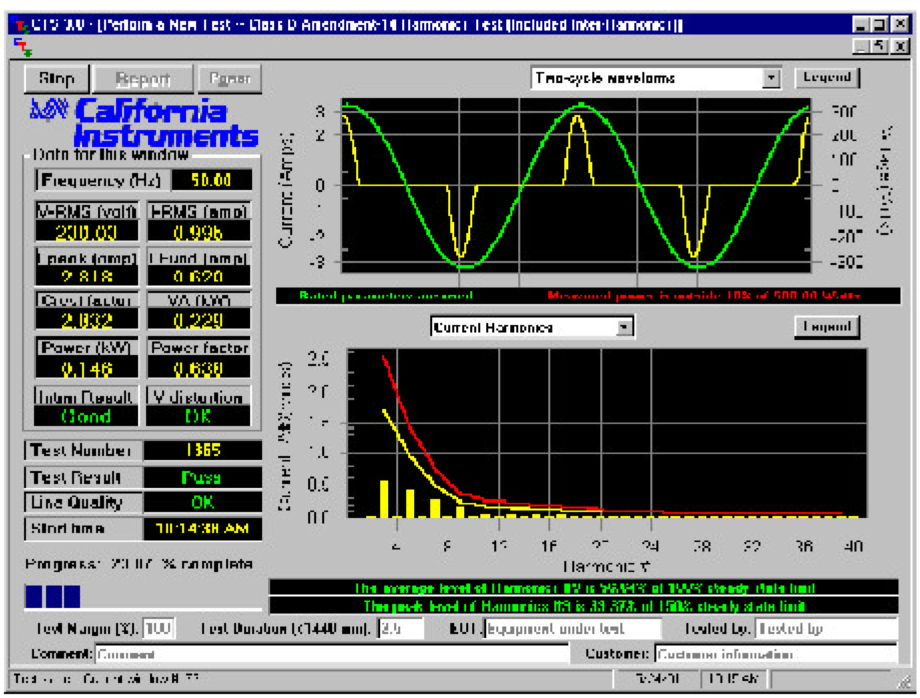


Figure 1 shows a screen capture of the voltage and current waveform of this 17 inch VGA monitor operating on 230 Vac - 50 Hz. The CTS system displays these waveforms and harmonic levels on the PC screen, along with the relevant power parameters and test conditions. Many TV's would exhibit a similar behavior, although their power level will generally be higher (for the larger screen sizes). Note that the electrical current (top graph) is drawn in almost pulse-like fashion, during only part of the half cycle. This behavior is typical of switching type power supplies, such as those used in TV's, monitors, audio systems, microwave ovens, printers, copiers, video games, etc. Note that the monitor consumes about 146 Watts and requires 0.995 Arms from the 230 Vac power distribution system. Its peak current demand is in excess of 2.818 Amperes, however. This "peaky" current waveform produces a lot of harmonics, which are shown in the bottom graph (bar), although they do not exceed the limits for Class-D type equipment (limit line in the bottom graph of Figure 1).

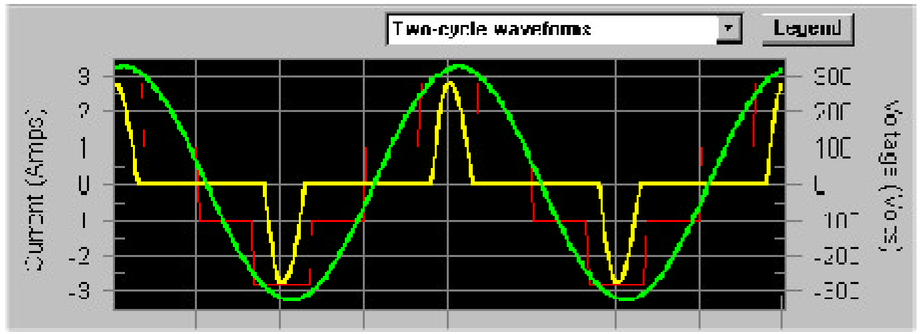
Figure 2

Result Summary

Phase	Harm #	Value	SS limit	% time > SS	Tran. limit	% of Tran. limit	Result
A	2	0.001	0.300	0.000	0.030	0.00	Pass
A	3	0.540	0.475	98.38[illegible]	0.713	75.73	Fail
A	4	0.006	0.300	0.000	0.030	0.00	Pass
A	5	0.425	0.266	99.147	0.330	106.05	Fail
A	6	0.006	0.300	0.000	0.030	0.00	Pass
A	7	0.285	0.140	99.360	0.210	136.11	Fail
A	8	0.005	0.300	0.000	0.030	0.00	Pass
A	9	0.151	0.070	99.574	0.105	143.80	Fail
A	10	0.004	0.300	0.000	0.030	0.00	Pass
A	11	0.047	0.049	0.000	0.074	63.34	Pass
A	12	0.002	0.300	0.000	0.030	0.00	Pass
A	13	0.032	0.34[illegible]	0.000	0.052	52.52	Pass
A	14	0.001	0.300	0.000	0.030	0.00	Pass
A	15	0.052	0.036	90.304	0.055	96.36	Fail
A	16	0.002	0.300	0.000	0.030	0.00	Pass
A	17	0.044	0.032	98.334	0.047	93.18	Fail
A	18	0.001	0.300	0.000	0.030	0.00	Pass
A	19	0.022	0.028	0.000	0.042	5[illegible].27	Pass
A	20	0.001	0.300	0.000	0.030	0.00	Pass
A	21	0.008	0.026	0.000	0.038	20.20	Pass
A	22	0.001	0.300	0.000	0.030	0.00	Pass
A	23	0.019	0.023	0.000	0.035	54.33	Pass
A	24	0.001	0.300	0.000	0.030	0.00	Pass

The CTS also stores and displays the test data in numerical or tabular format. Figure 2 shows the tabular display of the current harmonics recorded from a different VGA monitor by the CTS program. It shows that the 3 rd harmonic current level at 0.540 Amp is 87.5 % of the fundamental current level (0.617 Amp). As 3rd harmonic currents do not cancel out in neutral conductors, it can easily be understood that the neutral lines in an office building (with many monitors and PC's) can carry very high current levels, and thus potentially overheat.

Figure 3



Transformers may also overheat due to harmonic, currents and motors are affected negatively as well. Several of the higher harmonics have what is known as a negative phase sequence which can cause torsional vibrations in motors, and higher frequency losses may cause windings to overheat. Excessive harmonics therefore can affect several types of critical electrical equipment. Figure 3 shows the current waveform graph in more detail. Voltage and current waveform data for every acquisition window can be saved during each test. All data is written concurrently. The CTS can record a full measurement / analysis data set AND the associated voltage and current waveforms every 320 ms or 200 msec. One of the requirements stated in EN 61000-3-2 Amendment 14, is that transitory harmonic testing must be done over 10 or 12 cycles (200 ms at either 50 of 60 Hz) without permitting gaps in the measurement process. This no-gap requirement is to make sure that the analysis "catches" the worst case conditions, as transitory harmonics may come and go. By saving all acquired cycles to disk, the CTS software ensures complete archiving of all test data.

Therefore, the system not only performs a compliance test but also serves as an engineering data collection tool. The CTS file replay mode permits the user to inspect the behavior of the tested unit. In this mode, the test files can be stepped one measurement window at a time. As done for this document, test data files can be converted from their native binary files to ASCII text files for use in word processors and spreadsheets as desired.

Background on the EN61000-3-2 harmonics standard

There are numerous case histories of serious problems caused by excessive current harmonics. Transformer overheating is probably one of the more common events. Transformer failure in turn leads to power outages for whole neighborhoods and/or factories and businesses. Some events can even upset the control system of the high voltage grid, leading to widespread power failures which include many states or even sections of a country. Overheated neutral lines have caused fires in office buildings, and sensitive electronic equipment has failed because of short voltage dips caused by other "misbehaved" electrical equipment. As electrical power has become such an integrated part of our life, standards to assure its quality have become just as necessary as safety standards.

As mentioned earlier, harmonic currents have negative effects on electrical equipment. Efforts to limit harmonics and set some standards date back to the 1930's. The International Electrical Committee's (IEC) Technical Committee 77 (TC77) formulated its concept for a standard covering current harmonics at meetings held in Moscow (1977) and The Hague (1979). This work culminated in IEC 555.2, first published in 1982, and revised in 1984, 1986, and 1991. In the process, a Euro Norm called EN 60555.2, based on one of the intermediate revisions, was released. In December 1993, TC77A submitted a further revision document, known as Central Office no. 41 (CO-41), for approval. This document was approved by a majority of IEC member countries, and thus became EN 61000-3-2. The standard is also referred to as IEC 61000-3-2 and is identical to CO-41. We will use the official EN 61000 designation in this document.

Euronorm EN 61000-3-2 and the national counterparts, are legally enforceable versions for the EU countries. There are European Standards for just about every type of consumer product, from toys to tools and electrical apparatus. After passing the applicable tests, the manufacturer is entitled to attach a so called CE mark, approving the product for sale throughout the European Union. Once the CE mark is obtained, a manufacturer no longer has to pass testing in each individual country. In practice, things don't work smoothly yet, as the EU hasn't totally completed its internal harmonization process. One example is the enforcement date for EN 61000-3-2 3 (IEC 61000-3-2) for harmonics testing. The original goal was to have the new standards in force throughout Europe by Jan. 1, 1996. This later became Jan. 1, 1997, and then August 1998. Some countries (manufacturers) complained that they would not be able to meet the more aggressive time tables, which caused the mandatory enforcement dates to be shifted. This ultimately resulted in publication of Amendment 14, which is now applicable throughout the CENELEC countries, even though the prior (last revised in 1998) version of the EN 61000-3-2 standard may be used until January 1, 2004.

The intent of the EN 61000-3-2/3 standards is to force manufacturers to produce products that "behave well" when connected to the supply system. This implies that the electrical system quality is not deteriorated beyond specified limits by the operation of the electrical product. Electrical products have to be tested to verify conformance with specific limits. As the EC has made conformance to EN 61000-3-2/3 mandatory, product testing to these standards has become mandatory as well. Note that these "product power quality" standards therefore are aimed at preventing power quality deterioration.

Differences between IEC555.2 and EN61000-3-2

The IEEE-Std-519 (1992) is more comprehensive in its approach, but was not intended as a product testing standard, as it deals with power quality issues in a much broader sense. Its origins go back to the 1970's, with the first version being published in 1981. Product testing standards for the US are expected to evolve in the next couple of years. The EU had the short term demand to unify testing standards amongst member countries and, as such, is a few years ahead of the US and Japan, in the process of ensuring future quality of household power distribution systems. The publication of Amendment 14 of the EN 61000-3-2 standard covering both 50 and 60 Hz is an important step toward harmonization of standards between Europe, the USA and Japan.

EN61000-3-2 Amendment 14 Test Classes & Limit

The differences between EN 60555.2 and EN 61000-3-2 touch mainly on three areas. These are the scope/applicability of the standard, the fact that IEC 555.2 did not have a Class-D category, and the slightly different limits for Class-C (lighting products). From the early days of IEC 555.2, the standard was directed mainly towards products "purchased by the general public" in other words consumer products. Initially, professional products with a limited customer base were excluded. The CO-41 document changed this scope to include all electrical products with a rated current of up to 16 Amperes per phase. Therefore, most test & measurement equipment, communications gear, and industrial products, fall within the scope of EN 61000-3-2.

The broader scope of EN 61000-3-2 is especially important for Information Technology (IT) equipment. Products like PC's and fax machines were deemed professional products only 10 years ago, while they are consumer products today. The wording of EN 61000-3-2 removes the interpretation ambiguity that IEC 555.2 permitted. Whereas IEC 555.2 had a separate test class for TV's, this category (with some modifications) was expanded into a family of Class-D products in the new EN 61000-3-2. Since this class D covered a broad scope of products and it's limits are a function of the power level, many products were unable to meet this new requirement. Based on industry pressure, the IEC published Amendment 14 to the standard, which considerably narrows the range of products that have to meet class D limits.

The standard defines four (4) test classes, Class-A, B, C, and D, each having their own harmonic current limits. Classes B, C, and D describe specific products and product families, and all other products and motor driven equipment are automatically categorized as Class-A equipment.

The limits for Class-A and Class-B equipment are given in Amp rms (and so is the TV category of IEC 555.2). Class-C and Class-D limits vary with the power level of the tested product. Other than the 2nd harmonic in Class-C, there are no limits for even harmonics in either Class-C or D. Also, the 3rd harmonic limit of Class-C depends on the product's power factor. The limits for each class, including the TV category of IEC 555.2, are shown in Table 1.

Class-A includes all motor driven equipment, many domestic appliances, and 3 phase equipment.

Class-B includes all portable electric tools operated directly from 230 Vac - 50 Hz.

Class-C includes all lighting products, including dimming devices, with input power > 25 Watts
Note that EN 61000-3-2 was also amended to include limits on low power lighting products below 25 Watts (Compact Fluorescent Lamps). For these products, the 3rd harmonic current must be < 86% and the 5th harmonic current must be < 61% of the fundamental current.

Class-D includes PC's, PC Monitors and Televisions with a rated power level between 75 and 600 Watt.

Note that the current waveform envelope that used to apply under the previous EN 61000-3-2 Harmonics standard for Class-D equipment as shown in Figure 4 (copied from the CTS screen for the 17" monitor test) has been eliminated with the publication of Amendment 14. The CTS system still allows testing to the old standard if desired, in which class an automatic class A versus D evaluation takes place and the operator is informed accordingly.

Table 1

Harmonic no. (n)	Class - A limits (both standards)	Class-B limits (both standards)	Class-C limits IEC1000-3-2 only	Class-D limits IEC1000-3-2 only	IEC555.2 limits for TV receivers (> 165 Watt)
	A rms	**A rms**	% of fundamental (PF= power factor)	mA/Watt of input power (75 - 600 W)	(max dc current < 0.05 A) **A rms**
2	1.080	1.620	2 %	n/a	0.300
3	2.300	3.450	30 x PF %	3.4 mA/Watt	0.800
4	0.430	0.645	n/a	n/a	0.150
5	1.140	1.710	10 %	1.9 mA/Watt	0.600
6	0.300	0.450	n/a	n/a	n/a
7	0.770	1.155	7 %	1.0 mA/Watt	0.450
8	0.230	0.345	n/a	n/a	n/a
9	0.400	0.600	5 %	0.5 mA/Watt	0.300
10	0.184	0.276	n/a	n/a	n/a
11	0.330	0.495	3 %	0.35 mA/Watt	0.170
12	0.153	0.230	n/a	n/a	n/a
13	0.210	0.315	3 %	0.296 mA/Watt	0.120
Even 14 - 40	1.84 /n	2.760 /n	n/a	n/a	n/a
Odd 15 - 39	2.25 /n	3.375 /n	3 %	3.85/n (mA/Watt)	1.5 /n (Amp)

Figure 4

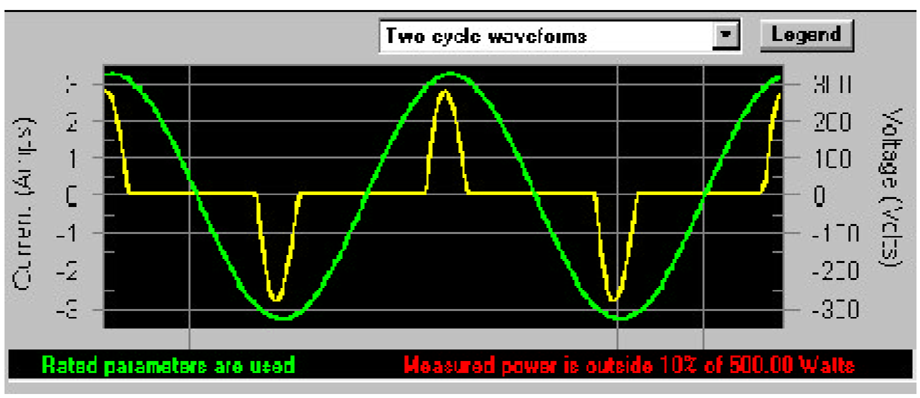


Figure 5

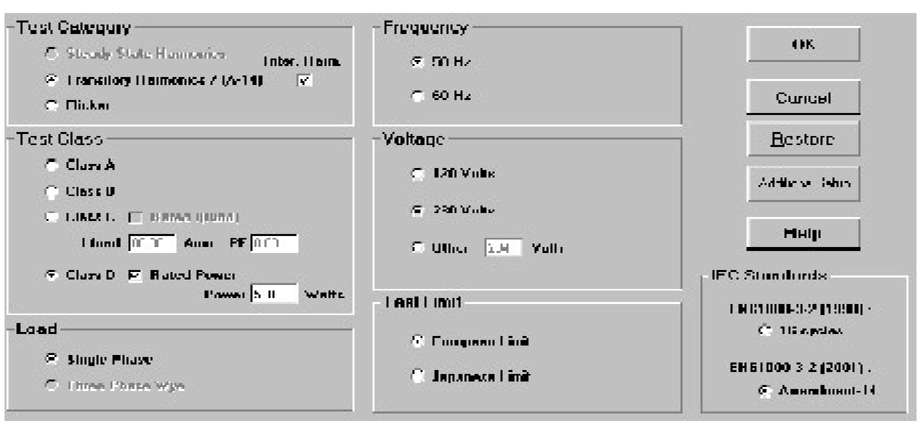


Figure. 4 shows the voltage (sinusoidal) and current waveform (peaky) of a typical EUT. The test class selection is made by the operator in the setup screen as shown in Figure 5. Note that under the new Amendment 14, the class D current template is no longer relevant to determine if an EUT is a class D product. Instead, only TV's, PC's and PC Monitors are class D if the rated power level is within the 75 - 600 Watt range and the measured power during the test is within 10 % of the rated power level stated by the manufacturer. If not, the EUT may be tested to Class-A limits. Alternative interpretations stipulate that no limits apply to class D products that don't meet the rated power level. In that case, no pass/fail analysis is done if the average power level is below the 75 W threshold. The CTS system can accommodate either method if desired.

True IEC-725 impedance or Programmable impedance option

Even though the CTS is available for different power levels, the operation is identical, irrespective of the power source type. In other words, operating the 1251RP-CTS is similar to the 5001iX-CTS. The only difference between the 1251RP and the "iX" is that the "iX" series permits the user to program a test impedance, while the 1251RP does not have this feature. The "iX" offers added flexibility, especially for users who have to test against the European EN 61000-3-2 and against the Japanese version with the same system.. Whereas the EN 61000-3-2 specifies a measurement circuit without a Reference Impedance (see next section), the Japanese version requires the use of a Reference Impedance when doing harmonics testing. Moreover, the impedance level for testing per the Japanese version changes, depending on the test voltage and circuit type. These different impedance levels reflect the Japanese power distribution system. The 'Japanese' limits selection in the CTS setup screen selects this Japanse method of harmonics testing.

When the test circuit for the EN 61000-3-2 was determined, the approach was to make sure that harmonics were acceptable, even in the worst case condition. As the Reference Impedance has an inductive element, it tends to suppress the level of higher frequency harmonics. By eliminating the impedance therefore, the EUT is permitted to induce a higher level of harmonic currents than would be the case if the device was connected to the power outlet in a home. The Japanese have taken what some describe as a more pragmatic approach, by permitting the reference impedance to be in the test circuit for harmonics testing.

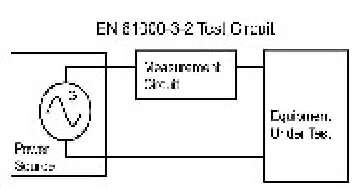


Figure 6

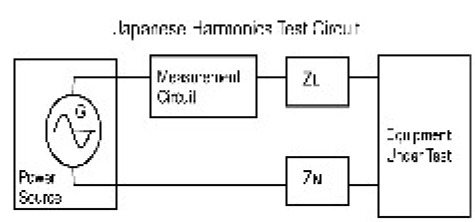


Figure 7

Test conditions and measurement methods

The old EN 61000-3-2 standard defines two basic test conditions, Steady State and Transitory (Fluctuating) State. Under Amendment 14, all products are evaluated using the transitory method. A further complication is caused by the fact that the limits for Class-C & D are proportional, as earlier explained. Whereas this does not cause any difficulties for products with a constant current/power level, the situation is less clear for products with fluctuating load levels. Most test systems implement so called dynamic limits, with the limits constantly being adjusted per the measured power (or the fundamental current for Class-C) while others use some average power level to set the limits. The latter systems determine this average power/current using some arbitrary method, and pre-test period. Thus different test systems implement different limits for the same (fluctuating power) products, which can result in one system PASSING a product while the other REJECTS it. Under Amendment 14, the manufacturer rated power level or current is used to determine class C and D limits, eliminating this issue.

A second issue for fluctuating loads is the way the previous harmonics standard (second edition) defined criteria for passing and failing the harmonics test. The old standard permitted the unit under test to occasionally exceed the 100 % limit, provided the harmonics never exceed 150 % of the limit. In fact, the unit under test was allowed to exceed the 100 % level for 10 % of the test time. The test time for fluctuating loads has to be at least 2.5 minutes, i.e. the harmonics can exceed the 100 % limit for 15 seconds in every 150 second (2.5 min) period. For longer test times, one can perform this test in 2.5 minute “time blocks” but another interpretation is to take just 10 % of the overall test time. Thus, the testing method for fluctuating loads is, to some extent, subject to interpretation by the test equipment manufacturer. The new Amendment 14 version of the Harmonics standard now requires the following limit evaluation:

> The average value for the individual harmonic currents, taken over the entire test observation period shall be less than or equal to the applicable limits.
>
> For each harmonic order, all 1.5 sec. smoothed r.m.s. harmonic current values shall be less than or equal to 150% of the applicable limits.
>
> Harmonic currents less than 0,6% of the input current measured under the test conditions, or less than 5 mA, whichever is greater, are disregarded.
>
> For the 21st and higher odd order harmonics, the average values obtained for each individual odd harmonic over the full observation period, calculated from the 1.5 s smoothed values may exceed the applicable limits by 50% provided that the following conditions are met:
>
> - The measured partial odd harmonic current does not exceed the partial odd harmonic current which can be calculated from the applicable limits.
>
> - All 1.5 s smoothed individual harmonic current values shall be less than or equal to 150% of the applicable limits.

Note that many existing Harmonics and Flicker test systems may require firmware and or software upgrades to conform to Amendment 14. Existing CTS users can upgrade by simply installing CTS software version 3.0. No firmware or hardware upgrades are needed for full compliance with Amendment 14.

The standard further describes general test conditions and measurement methods. Basically, the general test conditions are selected to ensure that the worst case harmonics are evaluated. In other words, the test has to include all different operating conditions for the EUT. The EN 61000-3-2 test is to be performed over a full operating cycle of the tested equipment. For fluctuating analysis, the minimum test period is still 2.5 minutes, or 150 seconds. If a full operating cycle takes 2 hours, the test period becomes at least 2 hours as well. During the harmonics test, the analysis has to be performed without any gaps in the measurement. Transitory harmonics testing (fluctuating analysis) requires analysis to be done every 200 ms (10 cycles at 50 Hz or 12 cycles at 60 Hz). The CTS does exactly that, and also writes the test results along with waveform data to disk. Therefore, the CTS program produces a 2.5 minute test file with 750 rows of data, 5 for every second. Note that the old standard may be selected if needed in which case the acquisition window used is 16 cycles (320 msec) and 3 to 4 records per second will be written to the test data file..

For longer tests, every 200 msec or 320 ms acquisition window is evaluated, but not every data set is written to the test file, unless limits are exceeded. If the equipment under test exhibits harmonics that exceed the limits, the CTS will write a number of data windows before the limit violation and a number of data windows after to disk at full speed, and then revert back to a slower recording rate. This implementation provides both pre and post event data while preventing excessive data file sizes.

Power source requirements for EN61000-3-2

Naturally, the power source is not allowed to affect the current harmonic levels. Since the “ideal” power source doesn’t exist, the EN 61000-3-2 standard imposes certain minimum power quality requirements in Annex A. Probably the most demanding requirement is that the voltage distortion must remain very low, even when testing a nonlinear load with high harmonic current content as depicted in Figure 1.

Maximum permitted H2 - H40 voltage distortion with EUT connected in normal operation ;

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

The CTS performs a continuous voltage quality check, to make sure that current harmonic levels are not affected. The “VTHD” indication (see Figure 1, page 7) indicates the voltage quality, and the test file is updated every 200 ms or 320 ms. with the same indication. Obviously, if current harmonics are 5 x the allowable limit, voltage quality doesn’t matter very much. It’s mainly for borderline cases where voltage distortion matters.

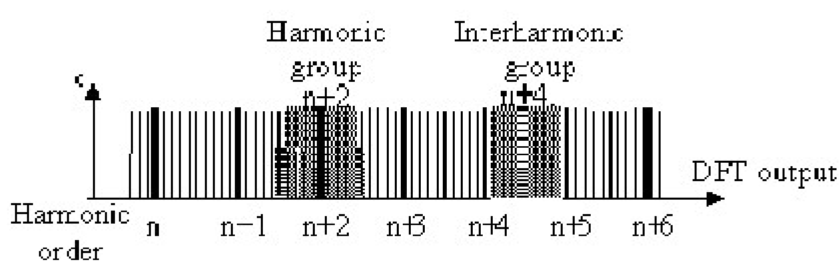
The standard covers equipment with current levels up to 16 Amp rms. Including the maximum harmonics per Class-B (Transitory), peak currents can be about 40 Amperes, hence the source must be able to deliver this power level. For systems that need to accommodate all types of EN 61000-3-2/3 testing, this higher current level needs to be taken into consideration. For testing specific products like TV sets or video recorders, the power source can be much smaller, like the 1251RP-CTS which handles 1250 VA and supports peak currents up to 13.8 Amp.

Impact of EN 61000-4-7

The standard also requires that the measurement circuit itself has minimal effect on the harmonic analysis, i.e. low source impedance, negligible voltage drop across shunts, high accuracy measurements, etc. The test circuit given in Annex - A of the standard is shown in Figure 6 on page 13. The CTS is provided with dual active HALL effect CT's, having virtually no voltage drop in the measurement system. The CTS signal conditioner isolates and scales the measurement signals and routes them to the DSP based analysis subsystem inside the PC. This analysis subsystem consists of a specialized plug-in card that requires a PCI expansion slot in the PC. The higher power CTS configurations with the "iX" source have been tested under worst case harmonics conditions (> 40 amp peak), and even then maintain very low voltage distortion, hence produce reliable harmonic analysis. The CTS can either bypass the impedance (OMNI) for harmonics tests, or insert the impedance as is required for Flicker testing.

To complicate matters further, the new Amendment 14 replaces Annex-B of the old 61000-3-2 standard with a reference to the EN 61000-4-7 Harmonic measurement standard. This standard deals with the method for acquiring and analyzing current harmonics. A new version of this standard is expected to be released in early 2002 which will now include interharmonics in addition to harmonics. This will require the inclusion of interhamonics in the evaluation of the EUT current against the class limits. For most harmonics and flicker systems, this will have a significant impact on the way data is acquired and processed. The DSP subsystem in the PC used by the CTS samples at very high rates, in excess of 200 kHz depending on the configuration, and thus can be used to produce accurate waveform and harmonic analysis, including interharmonics. This capability has been incorporated in revision 3.0 of the CTS software and can be enabled by the operator at any time. Note that the interhamoncis data is merged with the integer harmonic data as explained below and thus is not dis-

Figure 8



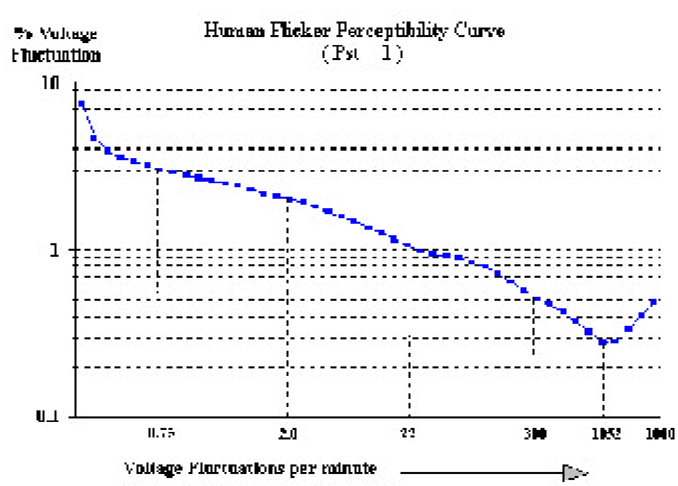
$$C_{ng}^2 = \frac{C_{10ng-5}^2}{2} + \sum_{i=-4}^{4} C_{10ng+i}^2 + \frac{C_{10ng+5}^2}{2} \quad \{50\text{ Hz system}\}$$

$$C_{ng}^2 = \frac{C_{12ng-6}^2}{2} + \sum_{i=-5}^{5} C_{12ng+i}^2 + \frac{C_{12ng+6}^2}{2} \quad \{60\text{ Hz system}\}$$

played separately. Per the new EN 61000-4-7 standard, interharmonics are "lumped in" with the (integer) harmonic subgroup level using a precisely specified algorithm. Although interharmonics may not necessarily have the cumulative effect as is the case with odd triplens (3rd, 9th , 15th, etc) they do generate heat, and adversely affect electrical gear. Hence the interharmonics are lumped into the adjacent integer harmonic level using the geometric averaging algorithm, similar to a RMS calculation, as given in Figure 8. This geometric average of the harmonic subgroup is filtered (using the 1.5 sec filter) and then compared against the applicable limits. The new standard also defines the algorithm to calculate just the interharmonic subgroup (see figure 8). Note that if the 16 cycle acquisition window were to be used, the algorithms would change somewhat, as the number of interharmonics from the FFT would differ. This is reflected in the different algorithms. Figure 8 shows the algorithm for a 200 msec. acquisition period as used by the CTS system and the graphical representation of this concept for a 50 Hz power system.

CENELEC Amendment-14 to EN 61000-3-2 moves many electronic products from test Class-D to the generally more relaxed Class-A. For remaining class D products, limits are now based on the manufacturer's "rated" power. This rated power is to be determined in accordance with the 1.5 sec filtered measurement method as given in the amendment. The same method applies to determine the Fundamental Current and Power Factor for Class-C products. The amendment defines measurement methods and harmonic limit comparisons that apply to both stationary and fluctuating harmonic analysis. Per the amendment, the normative Annex-B of EN 61000-3-2 is to be replaced by the measurement and analysis methods given in (the new) EN 61000-4-7. This new standard requires the use of a 200 ms acquisition window, and specifies algorithms to include interharmonics into the so called harmonic subgroups. The CENELEC Amendment therefore greatly affects compliance test systems. Especially manufacturers of Class-D products need to implement the new methods to determine what "rated" power levels they need to specify for their products. This applies also to manufacturers of lighting products (Class-C) for fundamental current and PF as well. Testing authorities and test laboratories should also take the changing requirements of EN 61000-4-7 into consideration. The CTS system is fully capable of supporting these new requirements.

Figure 9



Background on the EN61000-3-3 Flicker Standard

As the name indicates, the Flicker standard evolved from the requirement to reduce voltage fluctuations that cause irritating light flicker. Most of the complaints concerning light flicker were caused by heavy duty industrial equipment like arc furnaces. Products such as electrical welding machines, air conditioners, water heaters, and even bigger lighting systems can cause these voltage fluctuations. While the initial study mainly concerned voltage fluctuation levels at the point of common coupling (PCC) in electrical power distribution systems, the scope was later broadened to define acceptable fluctuation levels at the consumers premise.

Human sensitivity to light flicker

To determine acceptable voltage fluctuation levels, a large group of individuals was subjected to light flicker from the so called 60 Watt - 230 Vac -50 Hz reference lamp. The supply voltage to the lamp was varied to cause light flicker of different magnitudes and frequencies, and people would indicate when a given level was irritating. It turned out that the human eye-brain system has a particular sensitivity curve. Just as our hearing is most sensitive in the frequency range of 1000 - 4000 Hz, and tapers off fairly quickly for frequencies outside this range, we have a similar response to light flicker. This sensitivity curve is shown in Figure 9 on page 17. The percentage voltage change is given in percent on the vertical axis, and rate of change in cycles per minute (CPM) is given on the horizontal axis. The line in Figure 9 is known as the standard perceptibility curve, indicating a perceived flicker level of one (1.00). The "Pst" stands for "Perceptibility-short term", short term being 10 minutes in this case. The human eye-brain system is most sensitive for light intensity changes that occur at the rate of about 1052 changes per minute, or 8.77 Hz. Intensity changes of 3 % once a minute cause the same irritation level as a 0.3 % change at a rate of 8.77 Hz.

This Pst level of 1 was determined to be the threshold of irritability for the average human. Note that a single change of 3 % in a 10 minute period constitutes much less than a Pst of 1. As is easy to understand, the light flicker needs to repeat in order to become irritating. In other words, Flicker has a cumulative effect. After determining the human sensitivity curve, a measurement and evaluation method was developed to translate voltage fluctuation percentage and frequency into Pst. The methodology to evaluate voltage fluctuations was published in the form of IEC 868, and Amendment I to this standard. It describes the Laplace transfer function, used to convert the two variables (percentage and frequency) into instantaneous perceptibility "P". The Perceptibility number for every measurement (100 times per second) is categorized into classes, and through a Cumulative Probability Function (CPF) converted into Pst for every 10 minute observation period. So, when the IEC 555.3 standard was published it basically specified that electrical equipment should not be permitted to cause voltage fluctuation patterns which would result in flicker levels which humans perceive as irritating. The IEC 868 Flicker Meter method was specified as the standard method to calculate the Pst level.

As IEC 868 was amended and more experience gained, a long term Flicker evaluation was devised. This parameter is called Plt (Perceptibility long term), and is evaluated over a period of 2 hours. Whereas the maximum permitted Pst is 1.00, the highest allowed level of Plt is 0.65. In plain English; the average human can handle light flicker with a Pst value of up to 1 for 10 minutes, but if this continues for 2 hours at a level of 0.65, we still get irritated. Also, it was determined that electrical products should not be so "misbehaved" that they cause an instantaneous voltage drop ("dmax") of more than 4 %, other than when turned on the first time.

Finally, products cannot be allowed to cause the line voltage to drop in excess of 3 % for more than a second. The parameters to check the voltage drop are called “dt” and “dc” respectively. The “dc” parameter is referred to as “steady state voltage drop”. Amendment 1 to the EN 61000-3-3 Flicker standard increases the dc limit from 3.0 % to 3.3 %. Furthermore, the permissible dmax for certain types of products such as portable power tools has been increased as well. These changes took effect in late 2000 and are fully implemented in revision 3.0 of the CTS software.

Test conditions and measurement methods for Flicker

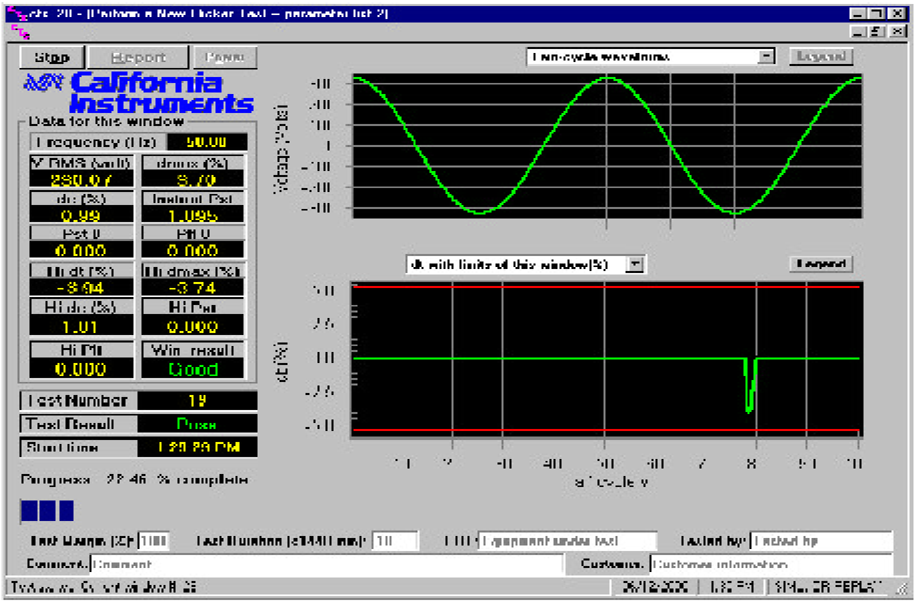
The basic measurement for Flicker is the RMS voltage level per half cycle of the 50 Hz fundamental frequency. Thus, the RMS level is measured 100 times per second. “dt’ is the change in percent (relative to 230 Vac) between successive half cycles. Flicker impression “P” is calculated from “dt” and then Pst is computed for every 10 minutes. Plt in turn is computed over 12 successive Pst measurements. For products that are tested for periods less than 2 hours, because their operating cycle lasts less than 2 hours, the Plt computation is still averaged over 2 hours. The calculation is done on the basis of a cubed averaging algorithm, as shown here.

$$Plt = \sqrt[3]{\frac{\sum_{I=1}^{N} Pst_I^3}{12}}$$

Depending on the test duration, “N” can be from 1-12 Pst measurement values (called Psti in this case). For example, after the first Pst measurement of 0.95, the resulting Plt will be the cubed root of 0.95 3/12 which equals 0.0714 1/3 or 0.415 . If this level were to persist for 40 minutes, the Plt will be the cubed root of 4 x 0.95 3 / 12 which equals 0.66, thus exceeding the 0.65 limit.

Figure 10 illustrates the CTS Flicker replay display at the instant a switching power supply is turned on. The graph shows the voltage drop of 3.9 % (across the Reference Impedance) due to the inrush current of the supply, and then the return to 230 Vrms. The total event which happened about 2 minutes into the test, takes only about 3 half cycles or 30 milliseconds. The graph displays 100 values i.e. covers a measurement period of 1 second.

Figure 10



For the Flicker test, the IEC 725 reference impedance is inserted into the test circuit as shown in Figure 11. The values for RA , XA , RN , and XN , are given in IEC-725 and also in EN 61000-3-3. For single phase testing, it is permitted to lump the resistive elements together (0.24 + 0.16) for a total of 0.4 Ohm and combine the inductive elements (0.478 + 0.318 mH) for a total value of 0.8 mH.

These impedance values differ for testing to the Japanese version. For current levels < 20 Amp in a 2 wire 100 V test, the total resistance is 0.4 Ohm, but the inductance is only 0.37 mH. For a 2 wire 200 Volt test, the resistance is 0.38 Ohm and the inductance 0.46 mH. These values include the source impedance, thus the OMNI reference impedance and the source output impedance constitute a matched system.

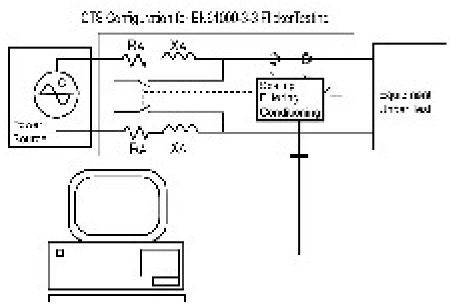


Figure 11

Power source for Flicker testing

Even though the Reference Impedance values include the output impedance of the power source, it is imperative that the source have excellent power quality and a low output impedance. In fact EN 61000-3-3 provides some specific parameters under the heading “Test Supply Voltage”. The standard states that the test voltage must be maintained within 2 % of the nominal value (under constant load) and that the total harmonic distortion shall be less than 3 %. If the measured Pst level is less than 0.4, any fluctuations of the supply voltage may be ignored. The specific overall measurement accuracy for Flicker parameters is +/- 8 %. This includes all errors, including those caused by deviation in the Reference Impedance and/or output impedance of the source. Consequently, it is important to keep the source impedance and all interconnect wiring resistance as low as possible. Again, the source with the CTS signal conditioning shown in Figure 11 consists of a matched system and, therefore, provides the basis for accurate Flicker analysis.

The different types of Flicker testing

Similar to the harmonics standard for Flicker testing, the product is to be operated so that the worst case conditions (voltage fluctuations) occur. The EN 61000-3-3 standard defines specific procedures for household products such as electrical cookers, hotplates, baking ovens, grills, microwave ovens, washing machines, dryers, refrigerators, mixers, and vacuum cleaners.

For a number of products, Pst and Plt do not need to be evaluated, i.e. only the “dt” and “dc” parameters have to be checked. Furthermore, if the particular products are controlled by manual (On/Off) switching, or are power cycled less than once per hour, the limits for “dt” and “dc” are multiplied by 1.33. Therefore, “dt” is permitted to reach 5.32 % while “dc” can be as high as 4 % in this case. This test condition applies to products such as vacuum cleaners and food mixers.

For consumer electronics, only “dmax” needs to be tested. Laser printers, copiers, and other similar products with a “standby” and “operate” mode, the Pst parameter is measured at the maximum operating/production rate, while Plt is measured in standby mode. Also hairdryers and portable tools are operated continuously for 10 minutes to obtain Pst, while Plt need not be evaluated. Thus, the CTS allows the user to select which Flicker test mode to run. Also, the user can select a test margin (Figure 10, lower left corner). For in-house pre-compliance testing, the test limits could be set to only 90 % of the actual limits. This provides some extra insurance that the unit will pass if CE mark testing is to be done later by an independent test house.

The test period generally has to include at least one full operating cycle of the equipment under test. As in the harmonics test mode, the CTS measures the data and writes them to a test file. Flicker test files have 100 ea. RMS voltage readings per line (1 second), followed by the calculated Flicker parameters and a time stamp. Because a test can extend over many hours, the CTS keeps track of the highest occurring values (i.e. a “peak hold” mode) and displays those, as well as writing them to file. Similar to the harmonics mode, the user may replay the complete test from this data.

CTS Flicker test data with synthetic impedance

When the EN 61000-3-3 standard was approved, the IEC-725 Reference Impedance was listed as a requirement in the test circuit. The California Instruments “iX” series power sources have a programmable impedance feature, which is also known as a “synthetic” impedance. There have been questions regarding the synthetic impedance’s effect on measurement accuracy. Some observations indicated that earlier synthetic impedance versions left a little to be desired.

California Instruments therefore conducted several comparative Flicker tests using the CTS with the actual IEC-725 impedance coupled with a 5001iX power source. Then the tests were repeated using the same CTS but bypassing the lumped impedance and using the programmable impedance instead. The 5001iX was programmed to emulate the IEC-725 impedance values. A precise test load was modulated On/Off at frequencies defined in IEC 868 / EN 60868-0. The Pst readings when using the synthetic impedance were between 1.5 and 2 % higher than with the lumped impedance (OMNI), hence they are well within the +/- 8 % tolerance permitted by EN 61000-3-3. Furthermore, repeated tests produced consistent results. Therefore, the impedance could be programmed to eliminate even this 1.5 - 2 % difference. The results are tabulated in Table 2. As follows from this data, the 5001iX with programmable impedance may be used for Flicker testing.

Table 2

Voltage Fluctuation in %	Modulation frequency in CPM	Theoretical Pst level	Measured with OMNI Reference Imp. per IEC-725	Measured with synthetic impedance using 5001iX
1.00	19.1	0.94	0.955	0.973
0.50	110.0	0.69	0.690	0.706
0.50	475.0	1.05	1.054	1.071
0.25	1052.0	0.91	0.920	0.935
0.25	1620.0	0.62	0.640	0.655

CTS System configurations

The CTS series was designed to provide a cost effective solution for in-house testing, thereby helping manufacturers to minimize the cost for obtaining CE mark verification, as well as speeding the process of verifying acceptable performance. The CTS is also the first system to generate extensive test data files, which assist product designers in identifying problem areas in their power supplies and power control circuits.

Table 3

Single Phase Systems				
	VA Power @ 230 Vac	RMS Current @ 230 Vac	Peak Current	Power Source
PACS-1	none	< 140.0	< 200.0	User supplied
1251RP-CTS	1250 VA	4.6	13.8	1251RP
3001iX-CTS	3000 VA	11.1	96.0	3001iX
5001iX-CTS	5000 VA	18.5	96.0	5001iX
Three Phase Systems				
PACS-3-75	none	75 / Ph	< 200 / Ph	User supplied
15003iX-CTS	15000 VA	18.5 / Ph	96 / Ph	15003iX
30003iX-CTS	30000 VA	37.0 / Ph	192 / Ph	30003iX

Conclusions

The IEC1000-3-2 and IEC1000-3-3 standards are expected to reduce the negative impact on power quality, as exhibited in recent years by modern electrical equipment. As a result of these standards, and the predecessor IEC555-2 and IEC555-3 versions, manufacturers will have to improve the behavior of their products so they will produce acceptable levels of harmonic distortion and minimize voltage fluctuations.

The member countries of the European Union and CENELEC have been the first major economic trading block to impose mandatory testing of electrical products for harmonics and Flicker, but other countries either have followed or will follow in the near future.

Appendix A: CTS Compliance Information

Introduction

This appendix discusses the implementation of the EN 61000-3-2 and EN 61000-3-3 standards in the California Instruments CTS system. Many potential users of compliance verification systems are concerned with the actual compliance to official standards and test methods. This appendix addresses these concerns with respect to the CTS system for both Harmonics and Flicker testing. In addition to a detailed discussion of the CTS system architecture and implementation, test data is provided to back up claims made in this document. In addition, test data is provided for the iX series of AC/DC sources which verifies AC source compliance with IEC test requirements of these models.

NPL Certified

The California Instruments CTS System has been independently certified to meet EN 61000-3-2/3 compliance by the National Physical Laboratory (NPL) in the United Kingdom. The National Physical Laboratory is the United Kingdom's national standards laboratory and is an internationally recognized authority on AC calibration. (http://www.npl.co.uk)

EN61000-3-2 Compliance Testing

The EN 61000-3-2 standard is an expanded/modified version of the earlier IEC 555.2 standard. Probably the most significant change concerns the broader scope of the new standard, and the Class-D testing requirements. The EN 61000-3-2 standard will have the force of law in the countries of the European Community (EC).

EN 61000-3-2 covers ALL electrical equipment with a nominal current of 16 Arms, and below. The older IEC 555.2 standard excluded professional equipment not intended for widespread use. The newer standard furthermore recognizes the negative impact that non-linear (low cost) power supplies have on power quality. Consequently the Class-D requirements seek to limit this negative impact. The standard provides for 4 test classes, being Class-A, B, C, and D. All lighting products with a power consumption of 25 Watt and higher, are covered in Class-C. All electric motor driven equipment is covered in Class-A, except for portable equipment intended for short term use, which is covered in Class-B. Lately, most attention has gone to Class-D, which covers equipment with a power rating from 75 - 600 Watt and having a specific current waveform.

Test limits and test conditions are given in great detail in the standard. Initially there was some confusion as to the exact interpretation of some of the standard's language. The publication of Amendment 14 at the end of 2000 has resolved most of these issues. Furthermore, IEC Working Group I appointed a Task Force which released a proposed revision for EN 61000-4-7, which addresses the areas that were thought to be subject to interpretation. This document takes into account that EN 61000-4-7 will go into mandatory effect, and thus the compliance verification of the CTS series was performed to cover the most stringent interpretation of EN 61000-3-2, including Amendment 14 and EN 61000-4-7.

EN61000-3-3 Compliance Testing

The Flicker standard EN 61000-3-3 has also been around for a number of years, in the form of IEC 555.3. This standard in turn relies on IEC 868 and its Amendment I, which describe the Flickermeter architecture and performance verification criteria. The newer EN 61000-3-3 standard expands on the IEC 555.3 version, and defines test conditions and test criteria for a variety of electrical products. Therefore, the Compliance Verification of the CTS series has taken both the IEC 868 architecture and Flicker accuracy testing methods, as well as EN 61000-3-3, Amendment 1 into account.

NIST traceability of Compliance Verification

For the Compliance Verification, equipment with NIST traceable calibration was used. The primary equipment consisted of relatively standard electronic instruments such as Digital Voltmeters, Frequency Counters, and Digital Oscilloscopes. In addition, a California Instruments model 2300CL Flicker Calibrator was employed. As follows, it is relatively easy to perform a NIST traceable calibration of the 2300CL Flicker Calibrator. Hence all methods utilized for compliance verification are NIST traceable.

EN61000-3-2 Harmonics Compliance Verification of the CTS series

The EN 61000-3-2 standard imposes rather strict requirements on the power source. The power source must not increase or reduce the current harmonic levels caused by the EUT. The measuring circuit and additional power source specifications are covered in Annex-A. Requirements for measuring equipment are defined in Annex B. The basic measurement setup is shown in Figure 12 below.

Figure 12

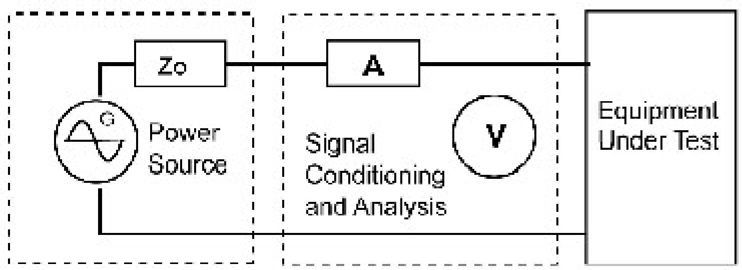


Figure 12 shows the configuration for a single phase CTS unit. This diagram shows the two principal elements, being 5001iX power source and the signal conditioning & analysis unit, and the EUT. The standard does not specify the power source output impedance Zo, but requires that it not contribute to the harmonic levels. If the voltage distortion limits as given below are maintained, the source does not affect the harmonic current levels.

The voltage distortion limits for the supply source are as follows;

0.9 % for harmonic of order 3 (150 Hz)

0.4 % for harmonic of order 5 (250 Hz)

0.3 % for harmonic of order 7 (350 Hz)

0.2 % for harmonic of order 9 (450 Hz)

0.2 % for even harmonics of order 2 - 10 (100, 200, 300, 400, 500 Hz)

0.1 % for odd harmonics of order 11 - 40 (every 50 Hz step from 550 Hz - 2000 Hz)

Voltage levels are to be maintained with ± 2 %, and frequency changes must be < ± 0.5 %

The CTS software monitors the source voltage distortion continuously, and updates both the test data file and its display for every 320 ms or 200 ms acquisition window. This way, the user is absolutely assured that the test complies with the source specification requirements as outlined in the standard. The 5001iX AC Source maintains its frequency within ± 0.05 % and the voltage level changes are < ± 0.1 %. In addition, both parameters are constantly monitored by the measurement section and the actual levels are written to the test data file.

In the existing EN 61000-3-2 standard, the analyzer's internal impedance Zm, is allowed to cause a voltage drop of max. 0.15 Vpk, therefore the EUT will receive the specified voltage within very close tolerances.

The CTS series employs two active Hall effect sensors which represent NO burden at all, hence they don't affect the measurements.

Both sensors have > 80 dB dynamic range, and one covers the low range while the other covers the high range. The combined effect is a current analysis circuit with > 100 dB dynamic range performance. An added benefit is that the circuit requires no fuses as the sensors will not be damaged, even if they are subjected to prolonged overloads of 200 Amperes. In fact, the power source output protection and mains supply circuit breakers will be triggered well before any damage occurs to the current measuring circuit.

The standard calls for steady state harmonic analysis with accuracy's better than ± 0.2 % of the rated current, or better than ± 5 % of the permissible limits for the specific test class.

The CTS series has a maximum harmonic analysis error ranging from ± 0.1 % for the fundamental (50 Hz) to a worst case ± 4.1 % for the 40 th harmonic, fully meeting the standard. The typical performance results in errors < ± 1 mA at the 40 th harmonic. This performance is accomplished through the tight integration between the 5001iX power source and the signal conditioning/analysis section. Calibration is done at the system level, and can be verified by the user through a NIST traceable DMM with suitable accuracy specifications.

Note that harmonic analysis accuracy can be verified through various methods. The CTS series utilizes Fast Fourier Transform technology to implement the Discrete Fourier Transform as given in the standard. Sampling is sufficiently high to produce accurate analysis results up to 6 kHz (3 times the required 2 kHz in the standard). Anti-aliasing filters are provided to filter out higher frequencies. Given the strict sampling synchronization in the system, only rectangular windowing with an acquisition cycle of 10 or 12 periods of the 50 Hz signal is used (200 ms acquisition cycle) as defined as the reference method in standard.

The 1.5 second time constant filtering of the fluctuating harmonic levels used in the CTS is in strict compliance with the requirements as given in EN 61000-4-7.

For Transitory harmonics (fluctuating) the CTS analyzes the data every 200 ms without gap or overlap in the data. This may be verified by the user, as the CTS produces a test file with data records including the time domain current waveform for every 200 ms or 320 ms data block. The user can replay the test record, i.e. analysis data AND the waveform data, and can also inspect the test data in detail. This permits the user to post process data, recalculate harmonic levels, perform statistical analysis etc. For a 2.5 minute fluctuating harmonic analysis therefore, the user gets 750 records for 200 ms windows (or 469 records for 320 msec windows). Each record contains instantaneous harmonic levels, actual (raw data) current waveform, and RMS voltage & current, frequency, Power Factor, peak current, and the fundamental current level in RMS.

These unique CTS capabilities provide the user with every piece of data that can possibly be needed to verify system performance. Hence there can be no dispute over conformance at any time, as the user can prove validity through post processing of the data. The integration of PC-DSP based analysis makes this possible.

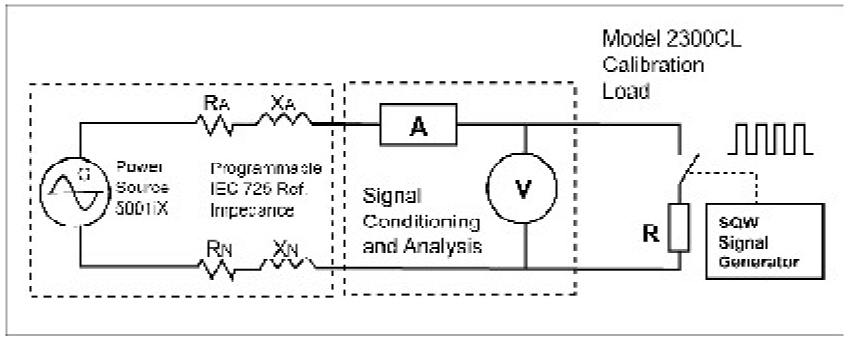
CTS compliance verification summary for EN 61000-3-2 Harmonics

Does the CTS AC power supply source meet voltage quality requirements ?	yes
Does the CTS continuously monitor source quality ?	yes
Does the supply & measurement circuit meet impedance requirements ?	yes
Does the CTS measure and process every 10, 12 or 16 cycles without gap/overlap ?	yes
Does the CTS meet the harmonics accuracy requirements ?	yes
Does the CTS calculate a linear average of all the harmonics during at test for comparison against the 100 % limit ?	yes
Does the CTS have real time limit calculation for Class-C and Class-D ?	yes
Does the CTS perform the Partial Harmonic Current comparison for H21 through H39 ?	yes
Does the CTS write spreadsheet compatible file for EVERY 200 msec (or 320 ms) data block ?	yes
Does the CTS have test replay showing the current waveform and harmonics data ?	yes
Is the CTS ready to comply with the requirements of the upcoming IEC 61000-4-7 revision ?	yes
Has the CTS system been verified by an independent test lab to meet its stated specifications ?	yes

EN61000-3-3 Flicker compliance Verification of the CTS series

The Flicker Meter consists of the CTS signal conditioner, AC source with built-in Reference Impedance per IEC-725, combined with the DSP based measurement subsystem in the PC. Compliance verification can be accomplished by modulating a resistive load, in exact accordance with the requirements as outlined in IEC 868 - Amendment I, and as specified in EN 60868 Table-I Rectangular Voltage modulation. The overall configuration is as given below in Figure 13. The California Instruments model 2300CL Calibrator or a similar instrument can be used for this purpose.

Figure 13



EN 60868 Table I

CPM	Mod F (Hz)	% Mod
0.10	0.0008	7.391
0.20	0.0017	4.584
0.30	0.0025	3.842
0.40	0.0033	3.540
0.50	0.0042	3.350
0.60	0.0050	3.169
0.76	0.0063	2.979
0.84	0.0070	2.867
0.95	0.0079	2.765
1.06	0.0088	2.679
1.20	0.0100	2.579
1.36	0.0113	2.484
1.55	0.0129	2.349
1.78	0.0148	2.294
2.05	0.0171	2.193
2.39	0.0199	2.091
2.79	0.0233	1.989
3.29	0.0274	1.893
3.92	0.0327	1.789
4.71	0.0393	1.679
5.72	0.0477	1.571
7.04	0.0587	1.456
8.79	0.0733	1.348
11.16	0.0930	1.244
14.44	0.1203	1.150
19.10	0.1592	1.062
26.60	0.2217	0.975
32.00	0.2667	0.942
39.00	0.3250	0.906
48.70	0.4058	0.866
61.80	0.5150	0.842
80.50	0.6708	0.782
110.00	0.9167	0.725
175.00	1.4600	0.635
275.00	2.2900	0.551
380.00	3.1700	0.500
475.00	3.9600	0.476
580.00	4.8300	0.423
690.00	5.7500	0.367
795.00	6.6300	0.321
1052	8.77	0.276
1180	9.83	0.283
1400	11.67	0.331
1620	13.50	0.402
1800	15.00	0.480

Table-I of EN 60868 covers all the possible calibration points for a Flicker Meter, from 0.1 voltage change per minute to 1800 changes per minute. By modulating the resistive load with the required frequency (as shown in Figure 13), voltage fluctuations can be created which in turn allow a Flicker Meter's performance to be verified for each of the calibration points. If a 60 Watt 230 Vac light bulb is subjected to the same voltage fluctuations, the resulting light Flicker would cause a short term Flicker level (Pst) of exactly 1.00, being the irritability threshold for the average human.

Voltage fluctuations must be measured every 10 ms and then the voltage change is computed as a percentage of the nominal 230 Volt. This difference is called "dt" and the standard permits a maximum change of 4 %, although some products are permitted to have as much as 5.32 % , for a maximum duration of 200 ms. If a product causes many voltage fluctuations, it will cause irritating light Flicker. The EN 61000-3-3 standard defines a 10 minute evaluation period for Ps(hort) t(erm). The voltage fluctuations are evaluated in accordance with the filtering and Laplace Transform characteristics outlined in IEC868, and the Pst level cannot exceed 1.00. In addition, the standard defines a Pl(ong)t(term) to be measured over 2 hours. Twelve consecutive Pst readings are used to calculate Plt. Even if the product has a shorter operating cycle, the Plt calculation produces a cubed average over 12 ea. Pst periods, and the non-measured periods are "deemed to be zero" as stated in EN 61000-3-3.

The CTS series was evaluated in exact conformance with this methodology. The selected calibration points were picked to include the most critical 8.77 Hz point, as well as several other frequencies that are commonly used as checkpoints.

For the tests, the 5001iX output impedance is programmed to the required Flicker impedance. This effectively inserts the IEC-725 compliant Reference Impedance in the circuit as shown above in Figure 13. The (non-inductive) resistive load is modulated at the appropriate frequencies, and at an exactly defined level. Note that voltage and current levels, as well as the frequency and modulation duty cycle can all be verified with NIST traceable instruments.

Test results 5001iX-CTS system per IEC868 Amendm. I

The standard states that overall accuracy must be better than ± 8 %, which includes any inaccuracies in the IEC-725 Reference Impedance, as well as measurement errors. As follows from the table below, the CTS accuracy is well within the required tolerance levels.

Table 4

Modulation Level in %	Modulation Frequency	Programmed Pst level	Measured Pst level	Error Percentage (must be < 8 %)
1.00 %	~ 0.16 Hz	~ 0.94	0.955	+ 1.6 %
0.50 %	0.916 Hz	0.69	0.690	+ 0.0 %
0.50 %	3.960 Hz	1.05	1.054	+ 0.4 %
0.25 %	8.767 Hz	0.91	0.920	+ 1.1 %
0.25 %	13.50 Hz	0.62	0.640	+ 3.2 %

Notes: The 0.16 Hz modulation was controlled manually.
Nominal voltage for all tests: 230 Vac - 50 Hz.

Because of the tight integration of the CTS DSP based acquisition inside the PC, the RMS voltage for every 10 ms sample period is written to a test file, along with all the calculated Flicker parameters which are derived from these 10 ms. measurements. The file has 100 ea. RMS levels (1 sec.) per line, in spreadsheet compatible format. This unique capability allows the user to post process all data, and verify exact compliance to the standard.

The standard also requires that the system measure steady state RMS levels (called dc) and the maximum voltage deviation (dmax) in a specific way. ***The CTS series follows these requirements and, in addition, has a unique real time display of these parameters, as well as for Ut, the instantaneous RMS voltage level for each 10 ms measurement period***.

The integration of PC/DSP based analysis of the CTS series makes these unique capabilities possible.

CTS compliance verification summary for EN 61000-3-3 Flicker Analysis

Does the CTS supply source meet the low output impedance specification ?	yes
Does the CTS Programmable Reference Impedance meet the IEC-725 requirement ?	yes
Does the CTS implement the Flicker Meter in accordance with IEC-868 ?	yes
Does the CTS measure and process data every 10 ms. without gaps ?	yes
Does the CTS meet the overall accuracy requirement of ± 8 % ?	yes
Does the CTS produce test reports with Pst & Plt graphs ?	yes
Does the CTS write spreadsheet compatible data files for ALL 10 ms measurements ?	yes
Does the CTS have real time display of voltage variations (dc - dt - Ut)?	yes
Can the user reproduce all Flicker calculations using the test files ?	yes

AC Source Compliance

Both Harmonics and Flicker tests require the AC source to meet specific output characteristics. California Instruments has gone through great lengths in developing the iX series of AC/DC power sources used in the CTS system to ensure these requirements were met. This section contains actual voltage distortion data taken on a production model 5001iX while driving a high crest factor load. This load actually exceeds the IEC harmonics Class A limits and as such represents a worst case situation for the AC source. The AC source should be able to drive a load that produces current harmonics at the maximum class limit levels and still have less than the maximum allowable voltage distortion. This requires that the AC source has a low source impedance. Any current harmonic will produce voltage drop across the source impedance which contributes to the voltage distortion. The lower the source impedance, the lower the contribution to the voltage distortion.

Table 5

Even Harm	Limit (% of Vrms)	Odd Harm	Limit (% of Vrms)
2	0.2 %	3	0.9 %
4	0.2 %	5	0.4 %
6	0.2 %	7	0.3 %
8	0.2 %	9	0.2 %
10	0.2 %	11 - 39	0.1 %
12 - 40	0.1 %		

Voltage distortion limits

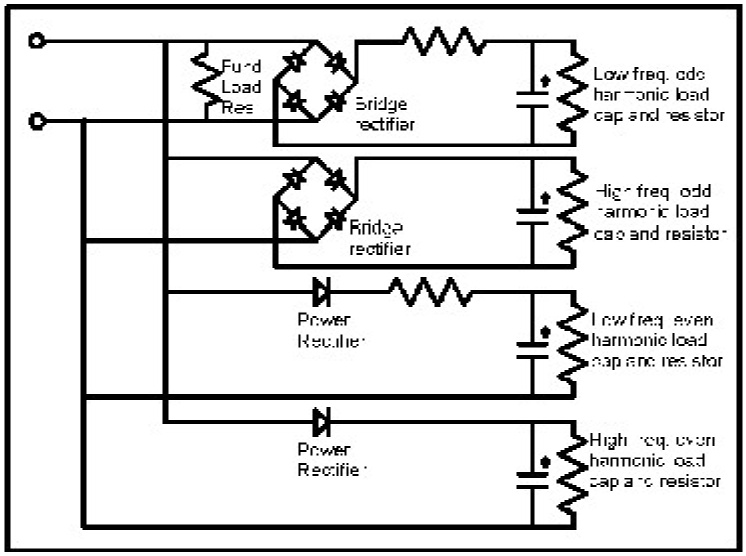
Maximum voltage distortion limits for AC source qualification are expressed in a percentage of the fundamental voltage amplitude for the first 40 voltage harmonics. If this maximum distortion level is exceeded at any time during the test, the test data becomes invalid. The specific harmonic voltage limits set forth by the EN 61000-3-2 standard are listed in Table 5. The total harmonic distortion (THD) of this waveform equals only 1.2 %.

Checking AC Source Distortion

Testing an AC source for voltage distortion under the EN 61000-3-2 worst case conditions requires the use of a complex load that produces current harmonics close to or equal to the maximum harmonic current limits allowed under the standard. Since the maximum load specified under the standard draws 16 Amps rms of fundamental current, the load must be rated for this current. A sample load that generates a current harmonic pattern close to the EN 61000-3-2 standard is shown in Figure 14. This type of load simulates conditions of a load that would still pass the requirement.

With the load connected, harmonic distortion measurements must be made. Since it is unlikely that each individual current harmonic of the load is exactly at the standard's limit, some interpolation may be required, i.e. ratio the voltage distortion up or down, assuming simple ohms law applied to the current, and a fixed output impedance over the small range considered.

Figure 14



Test Data for iX Series AC Sources

The California Instruments' iX Series of programmable AC sources is a family of high power, low distortion units offering very low dynamic output impedance. This makes them ideally suited for EN 61000-3-2 testing. The test data shown in Table 6 shows the actual voltage harmonics with the load depicted in Figure 14 connected. As some of the current harmonics exceed the EN 61000-3-2 standard limits, some interpolation is used. The load current values for each harmonic are shown in column 2. Column 3 shows the EN 61000-3-2 specification current limits. While this load would fail the test, it provides a good load for voltage distortion testing of the source as it is close to or over the limit on most harmonics. The actual voltage distortion of the AC source is shown in column four. The allowable limits are shown in column 5. If we interpolate these values for the difference between actual current harmonics and specification limits (column 6), the AC source easily meets the source requirements.

Conclusion

From this data it is clear that the iX Series exceeds the source requirements for the EN 61000-3-2 standard. For EN 61000-3-3 (Flicker) testing, the same source can be used as it offers a programmable output impedance.

The California Instruments Compliance Test Systems (CTS) use the iX Series AC sources and offer both EN 61000-3-2 and EN 61000-3-3 source and measurements for either single or three phase applications.

Before selecting an AC source or IEC test system for IEC testing, be sure to verify compliance of the AC source to the source requirement portion of the EN 61000-3-2 standard.

Test Data for iX Series AC Sources

Table 6

n	**Load Current**		**Voltage Distortion**		**Interpolated Distortion**
1	2	3	4	5	6
Harm.	Actual (I_A)	Spec Lim (I_L)	Actual ($A_{\%}$)	Spec Limit	D%= $A_{\%}*(I_L/I_A)$
2	1.853	1.62	0.078	0.200	0.068
3	3.837	3.45	0.380	0.900	0.342
4	1.139	0.65	0.072	0.200	0.041
5	2.226	1.71	0.130	0.400	0.100
6	0.463	0.45	0.057	0.200	0.055
7	1.073	1.16	0.112	0.300	0.121
8	0.126	0.35	0.019	0.200	0.053
9	0.700	0.60	0.065	0.200	0.056
10	0.190	0.28	0.096	0.200	0.141
11	0.718	0.50	0.089	0.100	0.062
12	0.254	0.23	0.050	0.100	0.045
13	0.605	0.31	0.083	0.100	0.043
14	0.252	0.20	0.037	0.100	0.029
15	0.418	0.23	0.083	0.100	0.046
16	0.173	0.18	0.020	0.100	0.021
17	0.371	0.20	0.093	0.100	0.050
18	0.104	0.16	0.040	0.100	0.062
19	0.357	0.18	0.082	0.100	0.041
20	0.104	0.14	0.026	0.100	0.035
21	0.279	0.16	0.074	0.100	0.042
22	0.119	0.13	0.041	0.100	0.045
23	0.228	0.15	0.066	0.100	0.043
24	0.119	0.12	0.034	0.100	0.034
25	0.209	0.14	0.069	0.100	0.046
26	0.098	0.10	0.032	0.100	0.033
27	0.165	0.13	0.072	0.100	0.057
28	0.063	0.10	0.035	0.100	0.056
29	0.105	0.12	0.055	0.100	0.063
30	0.058	0.09	0.027	0.100	0.042
31	0.069	0.11	0.024	0.100	0.038
32	0.057	0.09	0.025	0.100	0.039
33	0.054	0.11	0.023	0.100	0.047
34	0.043	0.08	0.027	0.100	0.050
35	0.041	0.10	0.009	0.100	0.022
36	0.030	0.08	0.017	0.100	0.045
37	0.040	0.09	0.028	0.100	0.063
38	0.013	0.07	0.008	0.100	0.043
39	0.052	0.09	0.021	0.100	0.036
40	0.014	0.07	0.016	0.100	0.080

iX Series AC source voltage harmonics under worst case EN61000-3-2 load

Appendix B: High Power Compliance Test

Introduction

Within the European Community (EC) there is a strong desire for standards that cover products up to 75 Amp/phase. Such standards permit manufacturers to follow the “standards route” to product certification, which is the lowest cost method to certification and (conditional) connection to the public supply system, without having to overcome major obstacles. Whereas TC77-SC77A/WG1 managed to produce a first CD (committee draft) for the harmonics standard IEC 61000-3-12, the next CD and the FDIS are not expected till late 2001. Working Group 2 (TC77/SC77A/WG2) on the other hand progressed faster, and IEC 61000-3-11 for Flicker tests up to 75 Amp per phase was published in August 2000. Even though the final version of the IEC 61000-3-12 harmonics standard up to 75 Amp per phase is yet to be generated, there is enough information at this time to consider its impact on a compliance test system.

Flicker testing per IEC 61000-3-11

The key requirements of IEC 61000-3-11 are as follows;

If equipment complies with the requirements of IEC 61000-3-3, it is not subject to conditional connection, and this may be declared by the manufacturer. Equipment which does NOT meet IEC 61000-3-3 when tested with the standard Reference Impedance is subject to conditional connection, and the manufacturer must either;

a) Determine the maximum system impedance Z max at which the equipment will still meet the Flicker limits given in IEC 61000-3-3, and declare this, and instruct the user to determine that the system impedance at the equipment connection point is less than this Z max . This may have to be done in consultation with the supply authority.

b) Test the equipment in accordance with section 6.3 of the standard, and declare in the equipment manual that this equipment is for use in premises having > 100 Amp per phase capability. This also must be declared on the equipment itself. The manual must also instruct the user to determine, in consultation with the supply authority if necessary, that the supply capacity is sufficient. As will follow from the foregoing discussion regarding IEC 61000-3-3, the voltage drop that is caused by electrical equipment depends on the current level AND on the system impedance. In the case of Flicker testing, the system impedance is fixed at the IEC 60725 Reference Impedance values. In networks for higher current equipment, the system impedance is typically less than the Reference. Impedance values. Thus, it stands to reason that a manufacturer can test the equipment with such lower impedance levels, and IEC 61000-3-11 includes specific formulas to convert the obtained dc, dmax, Pst, and Plt readings from the observed test level to the values that would have been obtained, had the standard Ref. Impedance been used.

The formulas are all straight linear conversions, where the ratio between Z ref /Z test is determined, and then used to multiply with the measured dc, dmax, Pst, and Plt values. In other words, assume the test impedance is 0.25 Ohm resistive and 0.25 Ohm inductive (the Z test values given in section 6.3 of 61000-3-11). In this case the ratio between Z ref and Z test is 1.33. Thus the measured dc level (etc.) is multiplied by 1.33 to obtain the dc level that would have been measured had a Reference Impedance been used. If the so translated parameter levels meet the limits of IEC 61000-3-3, the values for Z test could be declared. The advantage of having a lower test impedance is rather straight forward. Consider that a product that requires 75 Amp per phase will dissipate 75 x 75 x 0.4 = 2250 Watt in just the resistive portion of the Ref. Impedance. This translates to at least 3 x 2250 = 6.75 KW for a 3 phase Ref. Imp. unit, which is expensive to build. Reducing this to about half the size still requires a hefty cooling capability, but this is significantly easier to achieve at ~ 4 KW than at ~ 7 KW.

Note that the testing authority may use impedance levels that are lower than those given in section 6.3 of the standard. The impedance value of Z test must be selected such that the inductive component is between 0.5 - 0.75 times the resistive part. Also, it is recommended to select the impedance value such that the nominal voltage drop due to the equipment current is between 3 - 5 % of the test voltage. The IEC 61000-3-3 standard also provides an evaluation procedure, which permits the user to determine the maximum permissible impedance at which the equipment can be connected. This procedure must be used when the equipment fails the requirements of IEC 61000-3-3. The evaluation procedure includes formulas to determine four system impedance values;

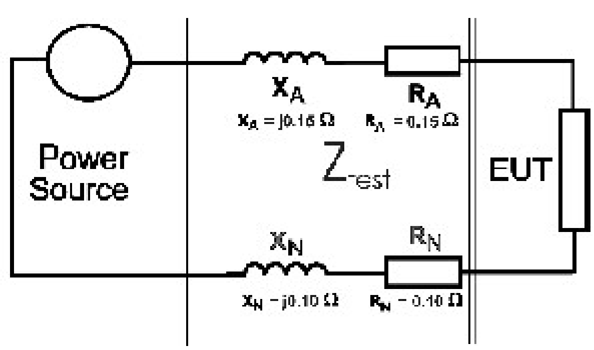
> Zsys1 = Zref x d max limit/d max Ref with d max Ref being the dmax value that is obtained if Zref is used.

Of course this d max Re value can be obtained using the conversion formula given on the previous page.

> Zsys2 = Zref x 3.3/dc Ref with dc Ref being the value that is obtained if Zref is used.
>
> Zsys3 = Zref x [1/Pst ref] 3/2 with Pst ref being the value that is obtained if Zref is used.
>
> Zsys4 = Zref x [1/Plt ref] 3/2 with Plt ref being the value that is obtained if Zref is used.

The lowest of the four calculated impedances is the value that the manufacturer must declare as the maximum permissible system impedance at the point where the equipment is to be connected. If the manufacturer wants to use method b; i.e. declare that the supply capacity must be at least 100 Amp, the standard calls for a test that utilizes specific Z test values. These values are given in Figure 15.

Figure 15



Harmonics testing per IEC 61000-3-12

The most important aspect of IEC 61000-3-12 is that the AC power source must have a low output impedance and drive > 150 Amp peak, so that the harmonics emissions are not affected. Even though the exact current harmonics limits are still being debated, fact is that IEC 61000-3-12 will have proportional limits; i.e, limits that depend on the product's power or fundamental current level. Thus the analysis system must measure both if it is to be expected that the user can later implement the limits for the test classes. Provided the measurement system can handle the 75 Amp rms (up to at least 150 Amp peak) the system could possibly be configured to perform analysis per IEC 61000-3-12. It must be assumed that the requirements given in IEC 61000-4-7 will apply to the measurement requirements for 61000-3-12, similar to the amendment of IEC 61000-3-2, and in fact the existing 61000-3-12 CD references IEC 61000-4-7. Thus, if the measurement system and the power source capability conform to these conditions, the software could in the future be configured to handle the limit comparison. The test setup is very similar to the requirements for IEC 61000-3-2.. Thus, the primary difference for both < 75 Amp Flicker and harmonics standards is the demand to generate clean power up to 75 Amp, and accurately measure and analyze these high power levels.

High Power Solutions

California Instruments is developing solutions for higher power IEC compliance testing that will leverage the technology used in today's CTS series systems. This will provide a smooth upgrade path for users of existing CTS systems that are faced with increasing demands for test capability. Contact the California Instruments sales department at sales@calinst.com for information on high power IEC test solutions.

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 APN119B 11/01