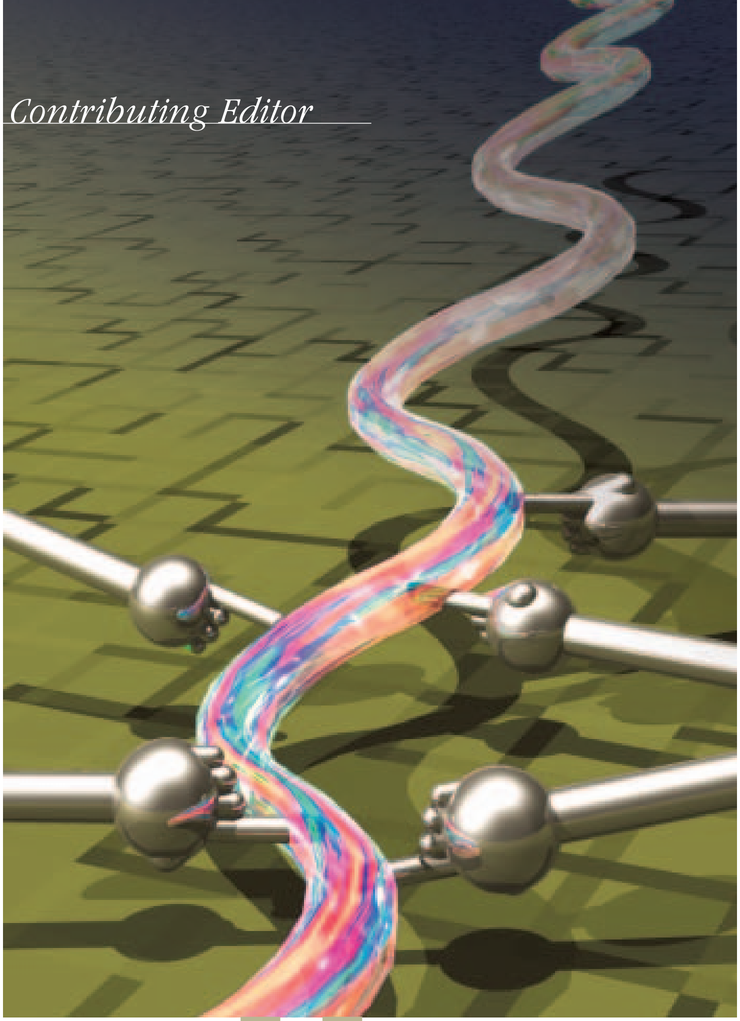
designfeature *By David Marsh, Contributing Editor*



PLUG IN

Safeguard ac powerline quality

TODAY'S PROLIFERATION OF ELECTRONICS CREATES POWER-QUALITY PROBLEMS THAT ARE SUFFICIENTLY SEVERE TO ATTRACT REGULATORY ACTION.

Illustration by Mike O'Leary

ALTHOUGH TODAY'S REGULATORY CLIMATE in Europe and elsewhere suggests otherwise, the issue of ac-powerline quality is far from new. As far back as 1974, IBM researchers George W Allen and Donald Segall conducted one of the industry's most authoritative studies into powerline artefacts by monitoring ac power feeds to equipment at 200 locations across the United States. Their results embrace 25 cities, recording over a two-year period the anomalies that disrupted their company's equipment—which then used relatively forgiving linear power supplies that ignore most line noise and tolerate small transients. Key findings from the study included transients accounting for 88.5% of all disruptions, with the worst 49% of such events showing oscillatory, decaying characteristics of relatively long duration. At 39.5%, the next most troublesome events comprised short-term impulse transients, such as those induced by lightning strikes; voltage dips and surges weighed in at 11%, and power outages surprisingly accounted for a mere 0.5% (**Reference 1**). But as the recent widespread power failures in Italy and the United States demonstrate, the electricity-supply system is still prone to catastrophic disturbances whose roots can prove difficult or even impossible to isolate.

Guarding against power failures is heavily application-dependent and commonly ranges from adding an uninterruptible power supply to your PC to installing a backup generator to a facility. It's also a matter of judgement about when this step becomes cost-effective. In the United States, the National Power Laboratory predicts 2.66 events/year of five minutes or longer duration of rms voltages less than or equal to 75% below nominal, and 1.52 events/year that last longer than 30 minutes. Data from the United Kingdom's Electricity Council shows that consumers can expect power failures of one hour or more 0.12 times/year in urban areas, and 1.11 times/year in rural areas. As one result of today's economic dependency on electronic communications, proposals exist for powering the Web from high-availability dc supplies (**Reference 2**).

But in recent years, power quality rather than availability has become the dominant concern of electronics designers and systems engineers alike—and, ironically, the profusion of electronic systems is the prime cause. At the time of IBM's study back in the 1970s, computers were rare, and most domestic, office, and light industrial equipment presented nominally sinusoidal current loads to the powerline. Now, virtually every address in developed countries houses an array of electronics, almost all of which employ some form of ac-to-dc voltage conversion. Left uncompensated, the bridge-rectifier/capacitor front-end in linear and switch-mode power supplies presents a highly nonlinear load to the ac line as the capacitor charges only toward peaks of the sinusoid, creating a pulse-current waveform (**Figure 1a**). This pulse current typically contains harmonics at small but significant energy levels beyond 1 kHz (**Figure 1b**). Multiplied by countless connected loads, such as PCs, monitors, and TVs, the effect is to create harmonic pollution and reduce supply-network capacity. Switch-mode converters can also generate complex frequency components that couple back into the supply line to create local disturbances of varying severity. Other everyday loads that create disturbances include fluorescent-lamp ballasts; filament-lamp dimmers and motor-speed controllers that use phase-angle control; and a range of industrial applications, from arc welders to variable-speed drives. Concern is such that European Union legislation now safeguards utilities and consumers by mandating power-factor- correction circuitry to decouple difficult loads (**Reference 3**).

AT A GLANCE

- ▷ Supply-line harmonic pollution compromises public safety.
- ▷ Europe demands that equipment meets emissions limits.
- ▷ Amendment 14 obsoletes the reviled Class D "special waveshape."
- ▷ Immunity tests safeguard equipment and personnel.
- ▷ Evolving test standards mandate flexible test equipment.

POLLUTION AFFECTS SAFETY

The problems that harmonic pollution can create are wide-ranging. From an electricity generator's viewpoint, the ideal load is a pure resistor, in which the current waveform mirrors the voltage envelope. Conversely, the requirement to supply substantial amounts of reactive power decreases network capacity as the current waveform moves further out of step with voltage. Therefore, generators must budget extra power to maintain stability, wasting energy as plants run inefficiently below capacity. Not least, generators see revenue losses due to the inability of consumer-premises watt-meters to accurately measure reactive power consumption. Generators supply apparent power (VA) but charge by the watt, so equipment that draws current out of phase effectively reduces the power level that's metered. There are safety implications, too; all power derives from three-phase supplies, in which the neutral current should ideally be zero. But, in severe cases, harmonic currents can create phase imbalances that impress neutral-line currents as high as 1.7 times phase current, causing components such as transformers, phase-correction capacitors, motor windings, and neutral-line conductors to overheat.

TABLE 1—IEC 61000-3-2 HARMONIC EMISSION LEVELS FOR FOUR EQUIPMENT CLASSES

Harmonic number	Class A limits (A, rms)	Class B limits (A, rms)	Class C limits (% of fundamental)	Class D limits (mA/W)
2	1.08	1.62	2%	N/A
3	2.3	3.45	30 times power factor	3.4
4	0.43	0.65	N/A	N/A
5	1.44	2.16	10%	1.9
6	0.3	0.45	N/A	N/A
7	0.77	1.16	7%	1
8	0.23	0.35	N/A	N/A
9	0.4	0.6	5%	0.5
10	0.18	0.28	N/A	N/A
11	0.33	0.5	3%	0.35
12	0.15	0.23	N/A	N/A
13	0.21	0.32	3%	0.296
14 to 40 (even)	1.84/n	2.76/n	N/A	N/A
15 to 39 (odd)	2.25/n	3.338/n	3%	3.85/n

From a consumer's view, line-voltage disturbances create events that range from the inexplicable to the obvious. For example, random supply variations can cause a whole raft of microprocessor-based equipment to reset unexpectedly. When many such devices interconnect, such as in an industrial-process-control application, control may be lost due to phenomena such as fluctuating earth-potential differences. But the most obvious effect is flicker, where small but repetitive supply-voltage fluctuations cause lighting units to modulate their brightness. Humans are remarkably sensitive to such changes. Studies show that the eye/brain system perceives voltage fluctuations of as little as 0.276% at 17.5 Hz to be just as irritating as 3% changes that repeat every 0.8 times per minute. Because fluorescent lamps have much shorter time constants than tungsten filaments, their flicker is especially irritating; and as well as causing annoyance, flicker can stimulate epileptic fits in susceptible individuals. These factors help explain why the flicker attracted scrutiny as early as 1951, when General Electric published acceptable limits data for generators in the United States. Today, a multitude of initiatives seeks to control flicker and other powerline phenomena, with common objectives of limiting harmful emissions and ensuring that equipment safely withstands supply-line disturbances.

As a result, there's a huge amount of interest from designers who wish to ensure that their products don't fall foul of the regulatory watchdogs. Your situation is vastly complicated by the morass of reports, recommended practices, and standards that now exist and that give every appearance of being in a continuous state of flux. Don't assume that you're alone if you can't seem to get a grip on statutory requirements and their developments; many hardened test-industry professionals find the going tough and, as often as not, argue among themselves about the way forward. First, it's helpful to know which bodies are involved in drafting standards and the relationships that exist between them. The principal source for EMC (electromagnetic-compatibility) publications is the IEC (Internation-

TABLE 2–IEEE 1159-1995 LINE-BORNE PHENOMENA FROM A MEASUREMENT INSTRUMENT'S VIEWPOINT

Categories	Spectral content	Typical duration	Typical magnitudes
1.0 Transients			
1.1 Impulsive			
1.1.1 Voltage	More than 5 kHz	Less than 200 µsec	
1.1.2 Current	More than 5 kHz	Less than 200 µsec	
1.2 Oscillatory			
1.2.1 Low frequency	Less than 500 kHz	Less than 30 cycles	
1.2.2 Medium frequency	300 to 2 kHz	Less than three cycles	
1.2. 3 High frequency	More than 2 kHz	Less than 0.5 cycles	
2.0 Short-duration variations			
2.1 Sags			
2.1.1 Instantaneous		0.5 to 30 cycles	0.1 to 1.0 per unit
2.1.2 Momentary		30 to 120 cycles	0.1 to 1.0 per unit
2.1.3 Temporary		2 sec to 2 minutes	0.1 to 1.0 per unit
2.2 Swells			
2.1.1 Instantaneous		0.5 to 30 cycles	0.1 to 1.8 per unit
2.1.2 Momentary		30 to 120 cycles	0.1 to 1.8 per unit
2.1.3 Temporary		2 sec to 2 minutes	0.1 to 1.8 per unit
3.0 Long-duration variations			
3.1 Overvoltages		More than 2 minutes	0.1 to 1.2 per unit
3.2 Undervoltages		More than 2 minutes	0.8 to 1.0 per unit
4.0 Interruptions			
4.1 Momentary		Less than 2 sec	0
4.2 Temporary		2 sec to 2 minutes	0
4.3 Long-term		More than 2 minutes	0
5.0 Waveform distortion			
5.2 Voltage	0 to 100th harmonic	Steady state	0 to 20%
5.3 Current	0 to 100th harmonic	Steady state	0 to 100%
6.0 Waveform notching	0 to 200 kHz	Steady state	
7.0 Flicker	Less than 30 Hz	Intermittent	0.1 to 7%
8.0 Noise	0 to 200 kHz	Intermittent	0.1 to 7%

al Electrotechnical Commission), which sets many international standards via its two specialist EMC groups: TC 77 (technical committee 77) and the CISPR (Comité International Special de Perturbations Radioelectrique). Their products include basic, generic, and product-specific specifications for domestic, commercial, and industrial environments.

In principle, TC 77 tackles general low-frequency emissions and immunity issues and produces most of the basic standards; CISPR focuses on standards that safeguard domestic appliances, IT, and radio-frequency equipment. Both groups also work with other IEC subcommittees to provide technical expertise when it's needed and extend relationships with organizations that include CENELEC (the European Committee for Electrotechnical Standardisation), the IEEE (the Institute of Electrical and Electronics Engineers), the ISO (International Organisation for Standardisation), and the ITU (International Telecommunication Union). Because the European Union keenly adopts and promotes standards that it perceives as useful tools for member states, a block of numbers from 60000 to 79999 is reserved for IEC publications intended for EN (European Normative) application. When IEC publications appear in the Official Journal of the European Communities, they assume legal status following a period of grace that's intended to give you time to meet new requirements. **Reference 4** includes a list of these harmonized standards as well as a link to CENELEC's useful guide numbers 24 and 25, which can help you understand when and how to apply EN standards to your products.

STANDARDS LIMIT POWERLINE EMISSIONS

Currently, Europe and the United States lead the world in developing test methods and practices to safeguard power-transmission and end-user equipment alike. But before considering some of today's requirements, it's worth reviewing the background to harmonic-emission problems. Although many disturbances are line-borne, potentially troublesome harmonics almost invariably emanate from end-user equipment. Such emissions can be even- or odd-order and may include interharmonics that have no integer relation to the fundamental powerline frequency. In general, lower order harmonics have the largest amplitude, with distortions that appear uniformly on both half-cycles creating only odd-order harmonics, such as the ubiquitous "triplen" series (third, sixth, ninth, and so on). Differences between the positive and

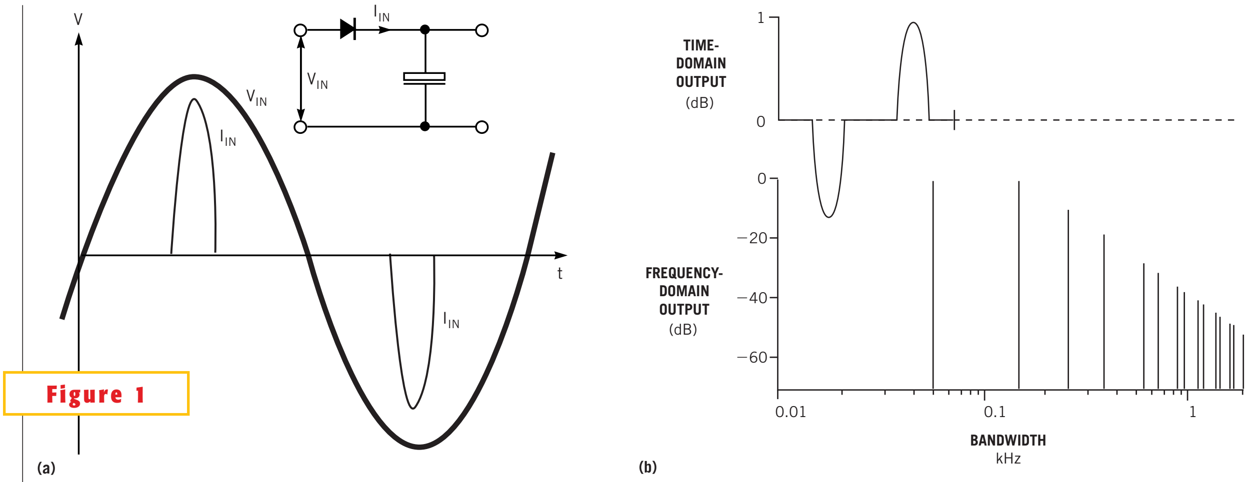


Figure 1

Because the input capacitor charges only toward the peaks of the ac line cycle, uncompensated power supplies present a pulse-current load (a). The pulse currents that result from nonlinear loads generate harmonics far beyond 1 kHz (b).

negative half-cycles or a dc component in the ac waveform caused by rectification create even-order harmonics. In general, emissions from similar nonlinear loads tend to add at the dominant low-order end up to the fifth or seventh harmonic, and higher order harmonics can tend toward cancelling themselves out; odd triplens (third, ninth, 15th, and so on) tend to add, however. Note that none of this science is exact, because measurement results depend on the mix of loads on a local spur, as well as the conditions on that spur; hence, uniform test methods are essential.

At first glance, you might find it surprising that any distortion of the ac powerline sinusoid creates harmonics that can extend beyond 100 kHz (although harmonics out to only the 40th order are normally of interest or subject to regulatory statutes). This situation is less surprising when you remember that every supply has a finite source impedance, so peaky loads are sure to impress disturbances of some magnitude. Clearly, this impedance depends upon local conditions and here comprises the sum of resistive, inductive, and (to a lesser extent) capacitive contributions from the local step-down transformer, through distribution wiring, and on to the outlet. Dating back to work in the 1970s, the IEC/TR3 60725 technical report records the background to defining the European reference impedance of 0.4+j0.25 that forms the basis of today's harmonic emission test limits throughout Europe (**Figure 2**). Notice that Japan and the United States currently use smaller values.

Regardless of region, the IEC/EN-61000 series of standards relating to interactions between equipment and the powerline currently attracts the most attention; crucially, designers wishing to sell into Europe must ensure that a huge range of products complies with them. Originally developed by the IEC and now enjoying legal status, these standards have endured a stormy reception from equipment makers everywhere. Objections range from the cost of ensuring compliance, through scope for interpretation of various requirements, to questioning whether compliance yields any practical benefits. But like it or not, power-quality regulations are here to stay. In a parallel development, the IEEE has published its "Recommended Practice on Monitoring Electrical Power Quality" (IEEE 1159-1995), and its single-phase harmonics task force (P1495) is working on recommendations to limit harmonic emissions from equipment with ratings of as much as 40A. Structurally, major components of the 61000 series comprise 61000-1-x definitions and methodology, 61000-2-x environment, 61000-3-x limits, 61000-4-x tests and measurements, 61000-5-x installation and mitigation, and 61000-6-x generic immunity and emissions standards.

The numbering system signifies the publication number, part, and section, respectively. (Hence, the -x suffix represents one of a number of sections.) Key areas for most electronics designers include 61000-3 sections 2 and 3, which set legally binding limits for harmonics emissions and flicker. Helping you to meet these limits, various sections of 61000-4 include useful tools for performing immunity tests for line-borne phenomena, as well as describing test-and-measurement methods appropriate to the European Union's directive on electromagnetic compatibility.

The emission limits that 61000-3-2 describes apply to all products that consume as much as 16A per phase, although grey areas include limits for professional and industrial equipment of more than 1 kW that are still under consideration. This situation has its background in a plethora of earlier standards, which the European Union's "new approach" program seeks to harmonize. Note that in the interim, you can't gleefully claim exemption from legislation, because generic standards will almost certainly apply. To obtain the CE (European Community) mark that enables you to sell controlled products within the region, you have to demonstrate good design practice. And, despite some views to the contrary, the authorities really don't want to make life difficult for you. It's their intention that you can satisfy legislative requirements by showing due diligence and demonstrating reasonable interpretation of any issues that arise.

Two routes are available for almost all products: self-certification and technical-construction file. Both require you to issue a Declaration of Compliance, which a senior company official, who is then liable for its accuracy, normally signs off. Self-certification requires "sound technical grounds" to justify the declaration, whereby you're responsible for ensuring

FOR MORE INFORMATION...

For more information on products such as those discussed in this article, contact any of the following manufacturers directly, and please let them know you read about their products in *EDN*.

Advance Electronics
www.aelgroup.co.uk

Agilent Technologies
www.agilent.com

AVPower
www.avpower.com

California Instruments
www.calinst.com

Chauvin Arnoux
www.chauvin-arnoux.com

Dranetz-BMI
www.dranetz-bmi.com

Elgar Electronics
www.elgar.com

Elspec
www.elspec-ltd.com

EMC Partner
www.emc-partner.com

EM Test
www.emtest.com

Fluke
www.fluke.com

Haefely
www.haefely.com

HV Technologies
www.hvtechnologies.com

Infratek
www.infratek-ag.com

Kikusui
www.kikusui.co.jp

Laplace Instruments
www.laplaceinstruments.com

LEM
www.lem.com

Pacific Power Source
www.pacificpower.com

REO
www.reo.co.uk

Schaffner
www.schaffner.com

Schloeder
www.schloeder-emv.de

Summit Technology
www.powersight.biz

TTi (Thurlby Thandar Instruments)
www.tti-test.com

Voltech Instruments
www.voltech.com

ZES Zimmer
www.zes.com

STANDARDS ORGANIZATIONS

ANSI (American National Standards Institute)
www.ansi.org

CENELEC (European Committee for Electrotechnical Standardisation)
www.cenelec.org

IEC (International Electrotechnical Commission)
www.iec.ch

IEEE (Institute of Electrical & Electronic Engineers)
www.ieee.org

ISO (International Organisation for Standardisation)
www.iso.ch

ITI (Information Technology Industry Council, formerly CBEMA)
www.itic.org

ITU (International Telecommunication Union)
www.itu.int

the soundness of the techniques used to claim compliance. For example, you may contract out testing to an accredited test laboratory and employ its results. Or, you might obtain test results in-house and combine them with a technical appraisal of your product. The technical-construction-file route also involves some testing, together with an exhaustive technical review of the product. It's typically better suited to products that are difficult to test conventionally, such as individual modules within a system. Notice that you must engage a "competent body"—for example, a suitable test lab—to audit all technical-construction-files.

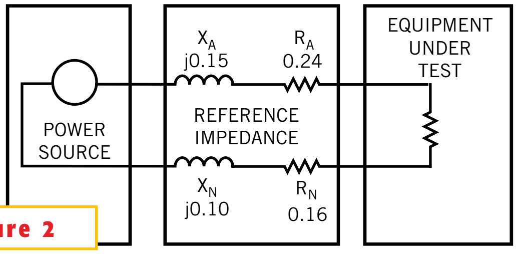


Figure 2

NOTE: TOTAL IMPEDANCE=0.40+j0.25Ω.

Technical report IEC-60725 sets the European reference impedance that forms the basis for harmonic-emission-test limits.

The equipment classifications and limits calculations that 61000-3-2 describes are widely applicable and group products into one of four classes. Class A comprises balanced three-phase equipment and everything else that doesn't appear in a subsequent class; portable electrical equipment, such as power tools, rank Class B; lighting products, including dimmers and compact fluorescent lamps, are exclusively Class C; and, until recently, Class D comprised equipment that's most relevant to electronics designers—devices that have fluctuating current-consumption profiles, such as those that use switch-mode power supplies. Equipment in classes A and B must meet fixed emissions limits that have their roots in EN60555-2 (61000-3-2's predecessor) and relate harmonic-distortion levels to the European reference impedance. For example, EN60555-2 specifies third-harmonic distortion for Class A as 0.85% maximum, and the reference impedance at 150 Hz is (0.42+(3×j 0.25) 2) 0.5, or 0.85Ω. Distortion of 0.85% in 230V ac is 1.95V, so the maximum third-harmonic current becomes 1.95V÷0.85Ω, or 2.3A. The Class B limits are simply 1.5 times those of Class A. By contrast, equipment in classes C and D are subject to limits that are proportional to their power consumption (**Table 1**).

Changes that CENELEC's Amendment 14 makes to 61000-3-2 have just come into effect; they reclassify much former Class D equipment into class-A. Originally designed to control high-impact distortion sources, such as TV sets, EN60555-2 sets harmonic emission limits for switch-mode supplies with acceptable conduction angles, thus defining the current waveform sufficiently well for electricity-distribution purposes. With the arrival of 61000-3-2, these limits spawned Class-D and its "special waveshape" for equipment within the 75 to 600W range. This special waveshape—to which you'll still see a multitude of references—divides the ac-line half-cycle into three portions of equal $\pi/3$ duration, with the first and last portions having rectangular limits of 0.35 times the peak current value of the centre portion (**Figure 3**). Current waveforms that remain within this envelope for at least 95% of the time became Class D, immediately including most electronics that use linear and switch-mode supplies. This change forced many redesigns to meet Class D's relatively strict limits, generating hostility from manufacturers of equipment that—unlike TV sets—isn't simultaneously operated by millions of consumers and thus presents a much lower impact to the powerline.

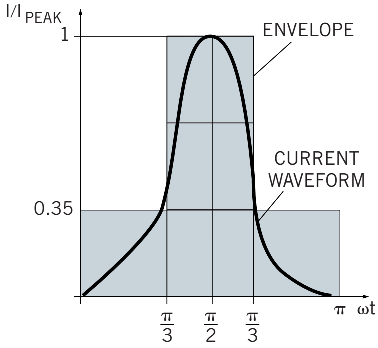


Figure 3

The "special waveshape" envelope forces much electronics into Class D in 61000-3-2's original specification.

As of Jan 1, 2004, Amendment 14's biggest change obsoletes the special waveshape and reclassifies Class D equipment to comprise just TVs, PCs, and monitors with maximum power levels of 600W; all other equipment that's not Class B or C becomes Class A. Class A's limits remain but are unlikely to present problems to most former Class-D products. However, Amendment 14 affects the harmonic-analysis method for Class D products that exhibit fluctuating power levels. Previously, and providing that it didn't exceed 150%, equipment under test could exceed the 100% limit for 10% of the 2.5-minute minimum test time. Because some equipment presents a fluctuating load for only a proportion of its operating time, taking longer tests and averaging the results over 10% of this arbitrary period may pass equipment that another interpretation fails. Amendment 14 dispenses with the 10% over-limit clause and closes this loophole. Equipment must now have an average harmonic level that's within limits for the entire test time, and, allowing for 1.5 seconds of filtering, every harmonic value from each test-sample window must be less than 150% of the limit. You now establish limits using a ratiometric calculation relative to the equipment's power rating; for example, a 250W power rating yields a third-harmonic value of 3.4 mA/W*250=850 mA. You must state the power rating, and this value must lie within ±10% of the actual value.

It's then critical to determine power ratings as unambiguously as possible. The general method measures each harmonic in turn for a predetermined sample-acquisition time; results for individual harmonics accumulate in bins over the duration of the test, which must be sufficiently long to provide better than ±5% repeatability. You then average each results bin using a 1.5-sec filter to find the maximum level of these smoothed samples, and this value becomes the power rating. Effectively then, Amendment 14 removes the discrimination between steady-state and fluctuating harmonics that 61000-3-2 makes. Also, references to the new 61000-4-7 standard are set to replace 61000-3-2's Annex B, which specified harmonic-component measurements. This publication defines requirements for instruments that measure powerline spectral components up to 9 kHz and distinguishes between harmonics, interharmonics, and other components. It de-

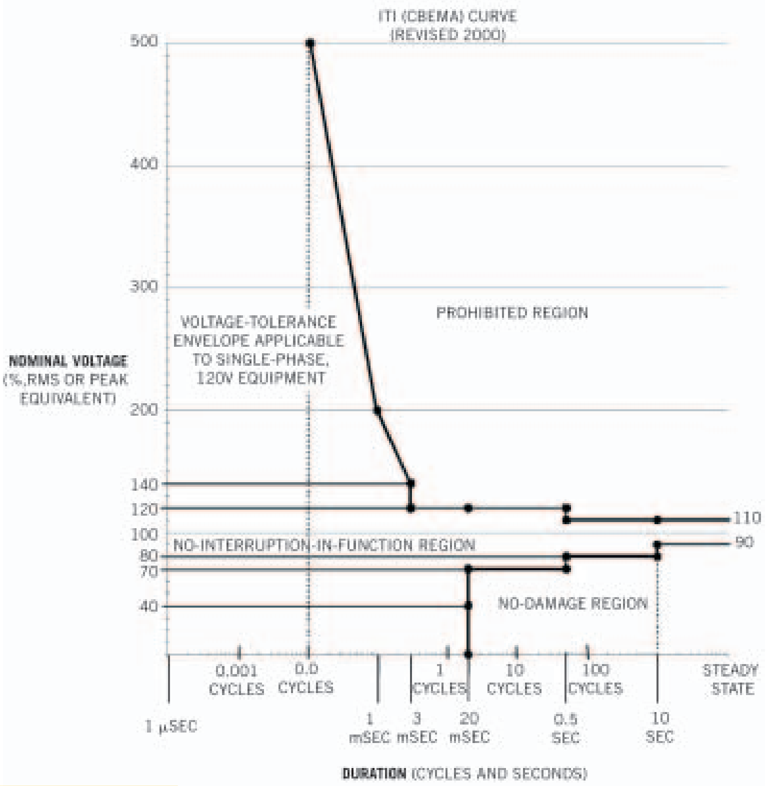


Figure 4 The CBEMA curve describes a voltage envelope that IT equipment should tolerate without malfunction (courtesy ITI).

mands a 200-msec sample-acquisition time that yields integer values of 10 or 12 line cycles for 50- and 60-Hz environments, respectively. The method-ology employs discrete-Fourier-transform techniques within a rectangular window and specifies algorithms to include interharmonics within the harmonic subgroups. If you're contemplating in-house testing, be sure to select test equipment that can accommodate such wide-ranging changes (see **sidebar** "Versatile equipment simplifies precompliance tests" on the Web version of this article at www.edn.com).

TESTS PRESERVE EQUIPMENT

Of course, it's just as important to ensure that your equipment withstands use within an electrically dirty environment. Line-borne phenomena that equipment must routinely withstand include voltage dips, surges, spikes and transients, and noise. The easiest of these to simulate are long-term voltage variations, such as the −15% dip that's permissible for 5% of the time according to the recent European 230V ac supply-voltage standard, EN50160. This specification requires a voltage stability of ±10% for 95% of the time, but has considerable leeway in surge accommodation. To qualify as such a voltage excursion, the supply must be 6% above the ±10% threshold value continuously for a minimum of 15 minutes—that is, 268V or more. The specification also permits waveform distortion of as much as 8% total harmonic distortion. In the United States, the ANSI C84.1-1989 specification specifies the steady-state voltage tolerances on the powerline and recommends that equipment tolerate a −13 to +6% voltage variation. The IEEE 1159-1995 specification summarizes line-borne phenomena from the viewpoint of measurement instruments (**Table 2**).

To test for adequate resistance to such events, domestic US equipment manufacturers often use the so-called CBEMA curve, which was developed by the Computer and Business Equipment Manufacturer's Association (now the Information Technology Industry Council). Last revised in 2000, this curve is a guideline that describes an ac-input-voltage envelope that most IT equipment can tolerate (with no interruption in function) (**Figure 4**). Major sections of the IEC/EN61000 series that similarly provide guidelines to help you check immunity from powerline artefacts include 61000-4-4, which specifies fast-transient and burst-immunity tests; 61000-4-5 for surge-immunity tests; and 61000-4-11 for standard test-and-measurement techniques for voltage dips, short interruptions, and immunity tests for voltage variations.

Mirroring the seemingly endless story of EMC-standards evolution, there are several developments that you might want to look out for in the 61000 series. For example, if flicker tests are important for your application, work that follows on from the IEC/EN60868 report of 1986 describes measurement practices and design requirements for flicker meters to enable tests to the limits that now appear in 61000-3-3. Covering functional requirements for flicker meters, IEC61000-4-15 provides a design specification that such instruments must meet, together with a method for evaluating their output. Elsewhere, the wide scope of IEC61000-4-30 embraces a specification for making measurements and interpreting results in both 50- and 60-Hz environments. This document tackles the full range of power-quality parameters, including supply-voltage frequency and magnitude, flicker, dips and surges, voltage interruptions, voltage and current harmonics and interharmonics, transient voltages, supply-voltage unbalance, and interference that arises from signalling on the supply voltage. First published in February 2003, its first committee draft amendment was scheduled for February 2004.□

You can reach Contributing Editor David Marsh at forncett@ btinternet.com.

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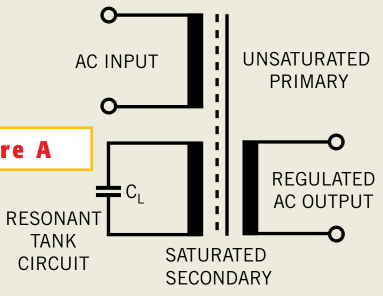
4. http://europa.eu.int/comm/enterprise/newapproach/standardization/harmstds/reflist/emc.html.

VERSATILE EQUIPMENT SIMPLIFIES PRECOMPLIANCE TESTS

If you're feeling lost in the morass of standards and ongoing changes, you're not alone. Test-industry professionals frequently criticize the standards committees for sins that they consider range from ambiguity to self-interest. Whichever view you take, there's no doubt that powerline-quality testing has become big business. Unless you're part of a large facility that can afford a calibration laboratory that's fully traceable to national standards, you're most likely to contract out final compliance testing to an accredited test lab. You can find lists of such labs via portals such as www.compliance-club.com and www.conformity.com. There, you'll also find resources including up-to-the-minute news and comments regarding regulatory changes. But you may consider it attractive to invest in some precompliance-test facilities to minimize the number of product iterations that you need to secure compliance. Such facilities are widely available—and for far less than you may have thought.

Powerline emissions tests first require a distortion-free power source with accurate reference impedance, which the public supply can't reliably furnish. Developed back in the 1930s and still in widespread use for general-purpose power conditioning, the classic ac constant-voltage source is a ferroresonant transformer that comprises a saturable core within a self-resonant circuit (**Figure A**). As the core saturates, it automatically adjusts the transformer's inductance and sustains an oscillation frequency that mirrors the ac line supply. Available in power levels of 100 to 15,000 VA, designs from a vendor such as Advance Electronics store sufficient energy to decouple the input from the output with interference attenuation as high as 75 dB. Regulation is typically around ±3% for a ±15% supply-voltage change with 90% conversion efficiency. Also, it's normal for separate windings to provide galvanic isolation, but, whatever the source, be sure to check this point if you're working on exposed live circuitry. You will need to add suitable reference impedance, which should be switchable to evaluate effects such as flat-topping the supply waveform under heavy load.

Figure A



The ferroresonant transformer exploits energy interchanges between a capacitor and an inductor to isolate and stabilize supply-line voltage.

Alternatively, vendors with application-specific ac test sources include Agilent Technologies, California Instruments, Elgar Electronics, EMC Partner, EM Test, Haefely, Kikusui, Laplace Instruments, Pacific Power Source, REO, Schaffner, and ZES Zimmer. Capabilities extend from a simple, nonisolated 1-kVA source, such as Laplace's nonisolated AC1000 for about €750, to Agilent's 6800 series, which combines source and measurement instrumentation for single-phase tests on equipment ratings up to 1750 VA. As a source, the 680x resembles a 45-Hz to 1-kHz arbitrary waveform generator and power amplifier, complete with output impedance that's programmable to 1Ω and 1 mH. You can perform preprogrammed tests or use Agilent's free GUI to design your own. The 16-bit measurement subsystem reports rms and peak ac, dc, and ac-plus-dc voltage and current levels; real, apparent, and reactive power; harmonic analyzes of voltage and current waveforms, including phase and amplitude up to the 50th harmonic; and total harmonic distortion. For around €8000, the midrange model 6812B sources as much as 300V ac/6.5A within its 750-VA rating, or ±425V dc/5A within a 575W envelope; GPIB and RS-232 interfaces are standard.

If the capability isn't built into the source, you'll also need a power analyzer. Alternatively, an array of additional vendors offers equipment of varying capability and application focus. Examples include AVPower, Chauvin Arnoux, Dewetron, Dranetz-BMI, Elspec, EM Test, Fluke, HV Technologies, Infratek, LEM, Schloeder, Summit Technology, Valhalla Scientific, and Voltech Instruments—to name a few. Variety ranges from handheld analyzers, such as LEM's single-phase Analyst Q70 for about €1400, through Summit's PK314M single- and three-phase power-quality-monitor kit for about €4300, to multifunction analyzers, such as Valhalla's 2600 series, which also measures parameters such as torque in single- and three-phase rotating machines.

Targeting industrial point-of-load power-quality-monitoring applications, handhelds such as LEM's Q70 perform an array of distortion, flicker, and energy measurements. The instrument also includes a datalogger and an overview mode that analyzes power quality to the EN50160 specification. Similarly costing around €1500, entry-level bench instruments include Thurlby Thandar Instruments' HA1600. In common with analyzers from other European vendors, such as AVPower and Voltech, this instrument targets measurements that 61000-3-2 and -3 require.

Many vendors also supply equipment for immunity testing. If you're designing a test lab, you may consider test systems from vendors such as California Instruments and Schaffner, which bundle the source and the measurement capabilities you need for a range of international standards. But whatever your choice, ensure that the hardware provides the means to perform appropriate and accurate tests and that the instrument's software is easily upgradable to support evolving requirements, such as interharmonics tests.

You may also spare a thought for calibration, as instruments that you use to support formal documentation must be traceable to national standards. Traditionally, power-analyzer and flicker-meter calibration requires systems that combine multiple reference sources and measurement instruments; inelegance apart, this approach imposes big measurement-traceability challenges. Primarily targeting calibration laboratories, Fluke's recent 6100A electrical-power standard combines programmable-voltage and -current sources with accuracies that approach 0.01%. The base unit allows you to set the output levels to 1 kV and 21A rms with six-digit resolution, and options extend the test envelope to 80A and three phases. Crucially, the phase between the outputs is programmable between ±180° with 3-millidegree accuracy. Output waveforms include simultaneous harmonics to the 100th order; rectangular or sinusoidal flicker with 0.0008- to 40-Hz modulation; fluctuating harmonics, from 0 to 100% of the fundamental harmonics' amplitude; interharmonics with a 16-Hz to 9-kHz range; and dips and surges of 1 µsec to 1 minute. The 6100A is available now starting at around €35,000.