Harmonics and Flicker

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Background

Maintenance of reliable performance of electric and electronic devices becomes increasingly important in a world where more and more people use all kinds of electronic devices, both at home and in their working environment.

Since 1987, products have had to comply with the EMC directive in order to be sold on the European market. A number of standards for emission and immunity have become mandatory from certain dates and are the basis for CE-mark approval of products. The main purpose of the EMC directive is to ensure that electronic devices do not disturb or become disturbed by other devices. In this context, an additional important aspect is to safeguard mains power quality.

This article discusses the emission standards EN 61000-3-2 for harmonics and EN 61000-3-3 for flicker. These standards are defined for products sold on the European market which have an input power of less than 16 amps at 230 V at 50 Hz mains. The need for limits for such disturbances tends to become global. Japan has already implemented a guideline very similar to the EN 61000-3-2 standard. Australia and New Zealand implemented EMC rules similar to the European EMC Directive. Negotiations between the United States and the EC have also taken place over a long period of time to develop uniform EMC regulations.

All over Europe, governments are setting up programs to certify that new products fulfill the requirements for the CE mark. In addition, it seems very likely that countries will also implement market control as a part of their competitive strategy. Every manufacturer plays an important role in making their products "cleaner and safer" to the power distribution network and to other products.

The first conference in marketing control was held in Stockholm last October. Penalties for products that are sold as compliant to the CE mark requirement, but are not, range within the European countries from fines, ban on sales and imprisonment for the manufacturer in the most serious cases.

Power distribution companies are already forced to explore sophisticated methods to deal with the increasing third harmonic problem caused, among other things, by the increased use of office equipment with switch-mode power supplies (Figure 1).

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Transitory Harmonics: A Case Discussion

The quality of distributed electric power has become a critical concern in recent years. This concern has grown with the improved energy efficiency of electronic household equipment and in commercial environments. The switch-mode power conversion technology that allows for more efficient use of electrical energy can have a negative impact on power quality.

In a normal three-phase power system, the third harmonic current, which is almost as great as the fundamental for class D objects, is added together in the neutral conductor. In a large office environment, there might be hundreds of switch-mode power supplies connected to the

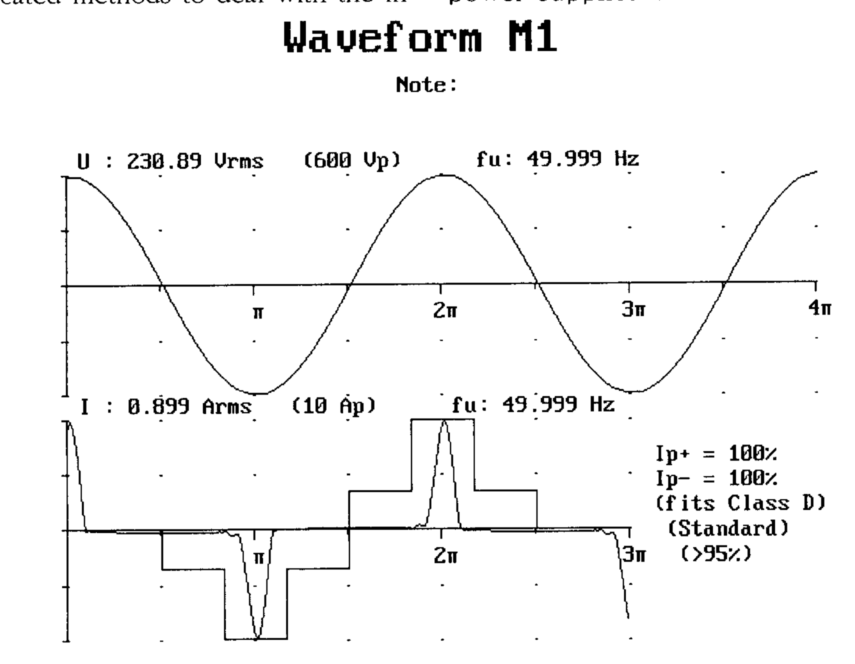

Figure 1. *A Typical Class D Waveform Caused by the PC System under Test.*

mains. Since the waveform is almost identical, the third harmonic current in the neutral could become bigger than the individual phase currents (Figure 2). This will cause voltage drops, increased losses in the electric installation, and a need for increased safety margins.

The lower limit for Class D objects is set to 75 W. This lower limit will be reduced to 50 W in March 1999. Objects with less power consumption do not need to comply with the EN 61000-3-2 standard.

For devices that have a varying power consumption in normal operation, transitory harmonics should be tested. Transitory harmonic currents may be 1.5 times the limits during maximum 10% of any observation period of 150 seconds.

For transitory harmonics, the classification of devices is not clearly defined in the standard. For example, a laser printer or a copy machine is normally a Class A device when operating, and a Class D device in standby mode. If defined as a Class A device, it will normally pass, but will often fail if defined as a Class D product. The power consumption is certainly higher in operation, but on the other hand, these devices are usually in standby mode.

Classes are defined as follows:

- *Class A:* Balanced three-phase equipment, and all other equipment not stated below.
- *Class B:* Portable electric tools, which are hand-held during normal operation and used for a short time only.

Classes A and B have fixed limits that are unchanging regardless of equipment behavior. These two classes correspond to groupings of equipment in the EN 60555-2 standard.

- *Class C:* Lighting equipment, including dimming devices. Fundamental current and circuit power factor are the variables that affect the absolute limits.
- *Class D:* Equipment with input power in the range of 75 W to 600 W that also exhibits a Class D waveform is subject to Class D limits. These limits are expressed in terms of mA/W.

Grouping equivalents to Classes C and D did not exist in EN 60555-2, and equipment that presently falls into these classes was tested to limits similar to those set for class A devices.

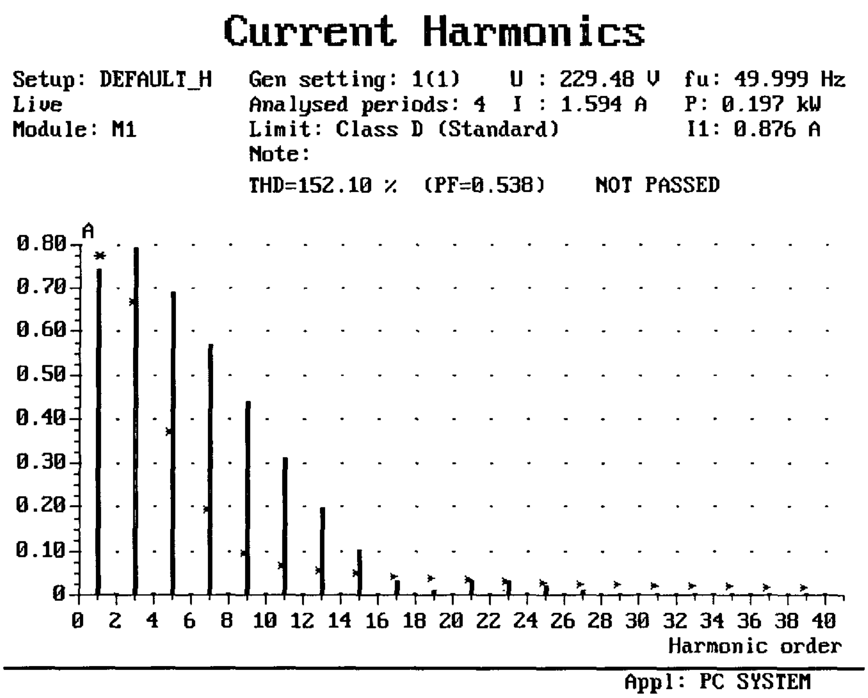

Figure 2. *Two PC Systems Were Tested in Series Connection. The 3rd Harmonic Is Nearly Twice (0.792A) Compared to 1 PC system (0.432A), Figure 4.*

A new class E has been proposed by SC77A/WG1 for professional equipment above 1 kVA. This class would also have limits in terms of mA/W but with no consideration to the waveform.

Another unresolved issue is how to interpret the directive for harmonics emissions for devices that belong to classes where limits are proportional to mains power consumption. Limits for these appliances are specified at different levels for each harmonic.

One interpretation could be that a single limit set is established for the duration of the test based upon a rated load condition for the equipment under test. It is common for this rating to be taken from the manufacturer's specification documented on the rear panel labelling.

Another interpretation could be that varying limit sets should be established during the test. These limit sets will track mains power consumption while the tested equipment is running through different operational cycles. As power consumption goes down, the limits will decrease. This will result in more stringent requirements at low power. In Figure 3, the instant cursor for each harmonic draws a bar for minimum and maximum value throughout the operational cycle, respectively. The amplitude of a bar is relative to the Class D limit with respect to power consumption calculated for every 16-period window of the test sequence. The rapid load changes for a PC system that fulfills the Energy Star regulations result in higher order harmonics. This is not the case if the steady state harmonics are measured for each mode (Figure 4).

For a lot of electronic equipment, having a varying power consumption and internal DC power supplies derived from rectification of the mains input means that the effects can be strong. These test objects can easily fail or pass compliance depending on the interpretation used.

Although the tested PC system did not pass the steady-state harmonics

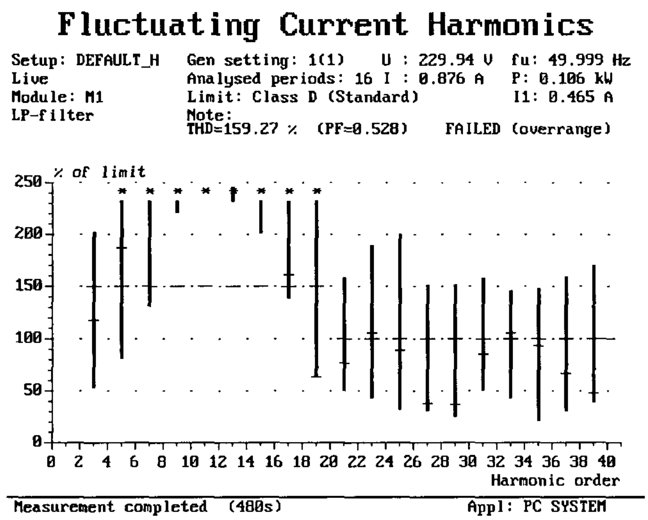

Figure 3. The PC System Was Tested During an Operational Cycle of 8 Minutes During Which the System Was in Sleep Mode Once.

measurement to Class D, it will fall into even more serious trouble if consideration is given to the Energy Star regulations and the fact that the PC system should be measured in an operational cycle. Figure 5 shows how the inrush current for the monitor from standby to operating mode will affect the limits and cause higher order harmonics.

The design of power factor correction circuits will become more difficult if an additional requirement is to handle the higher order harmonics at a rapid power change as for the restart of a monitor. This type of requirement for power savings and rapid restarts emanates from guidelines such as TCO 95 and Energy Star (Figure 6).

Japan adopted a guideline for harmonic measurements for products sold on the Japanese market. The purpose of the regulations is that the harmonic content generated by home appliances/general purpose instruments shall be reduced by 25% from today's levels. The guideline is close to the European regulations, with some important exceptions. Products that work at 110 V at 60 Hz shall be tested the same way as products working at 230 V at 50 Hz mains. The Japanese harmonic guideline also defines line impedances to be used when performing harmonics measurements.

Does a Monitor Produce Flicker?

Voltage fluctuations at low frequencies is unwanted in the power grid. The basic reason behind the flicker standard is to avoid a varying light intensity from normal lamps. The human eye is most sensitive for this in the frequency range from 0.25 Hz to 25 Hz with a peak at 8.8 Hz. The short-term flicker value, Pst, is defined with respect to the human eye sensitivity.

For power quality, this means that the worst flicker is caused by large varying loads such as arc furnaces, induction ovens, and compressors. Voltage fluctuations can also cause functional errors and other problems in a wide range of devices connected to the mains. All high power loads that vary in time will cause fluctuations that are likely to produce flicker. Even our normal home appliances like laser printers, microwave ovens, heaters, air conditioners and copiers have automatic turn on/off controls that will cause flicker.

Today, most PCs are compliant to the Energy Star requirements for saving energy. This means that a monitor will turn on and off depending on usage. Should a PC be CE marked as a system or not? A monitor by itself is a steady-state device, but in a system, it will become a typical flickering object. A reasonable conclusion must be that a PC system should be tested to the EN 61000-3-3 standard.

Figure 7 shows single-stage energy savings where the power is reduced to 50 W in sleep mode. (An old unit was used for this test). Today the power should be reduced to less than 5 W and a rapid restart (max 3 seconds to a readable screen) should be available. This causes a higher inrush current with a greater voltage

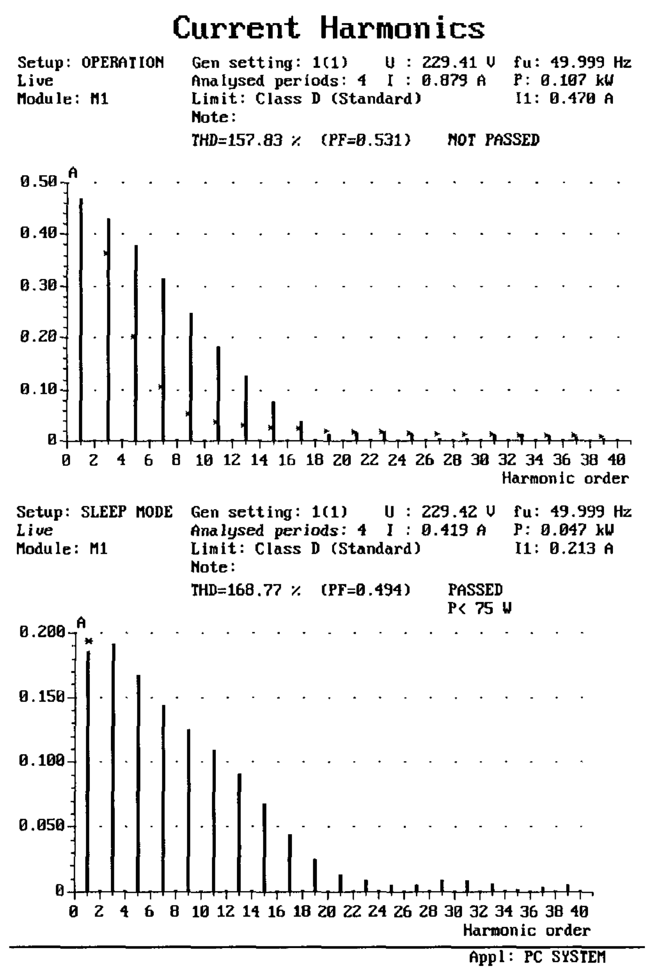

Figure 4. Two Snapshots for Steady-state Harmonics in Operating Mode and Sleep Mode to Class D.

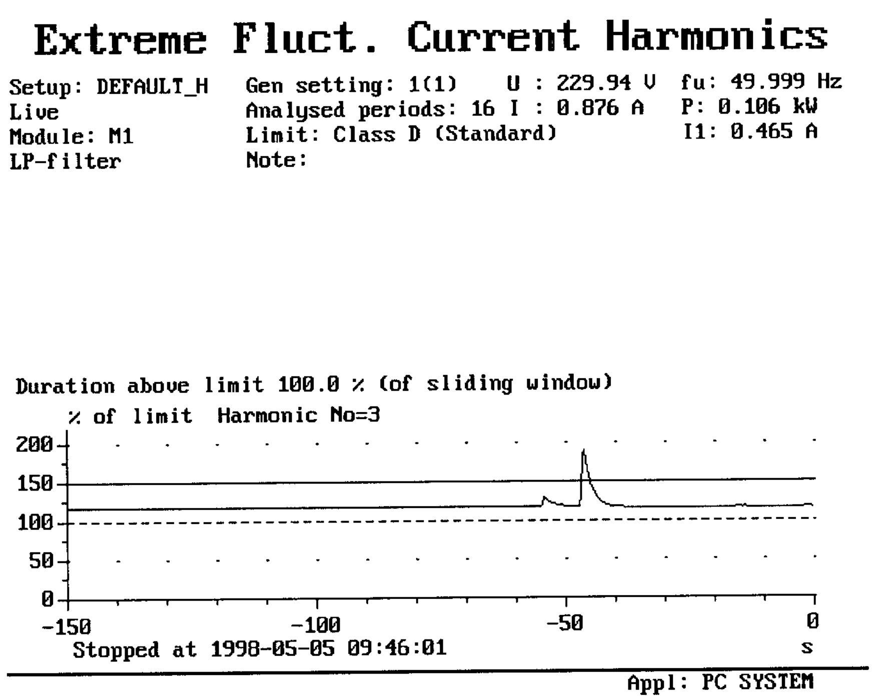

Figure 5. *3rd Harmonic Behavior Relative to the Class D Limits During the Operational Cycle. The power consumption was calculated for each 16-period window.*

change, dmax. Also, new limits for a two-step power decrease have been introduced by the EPA and the Swiss 2000 Guidelines for energy consumption. The result will be a flickering object that will affect other devices and the human eye. A PC system that is turned on and off produces a Pst value of 0.12 (Figure 8). It is behaving as a flickering device and falls under the EN 61000-3-3 standard. It is important to keep in mind that an office environment usually has several PCs connected in series that might affect the environment badly in terms of flicker if the power-down modes are set with short intervals.

Different product standards vary on whether a product should be tested strictly for maximum voltage change, dmax, and for flicker. For obtaining the short-term flicker value, the voltage change caused by power variations has to be measured. The determination of the flicker value is fully described in the standard EN 61000-4-15 (earlier EN 60868). The accuracy for a flicker test using a digital flickermeter basically depends upon the accuracy of the voltage change measurement. The EN 61000-3-3 standard basically defines two methods, *direct voltage measurements* and *power measurements*, for obtaining the voltage change, d (Table 1). Surprisingly, most solution vendors for EN 61000-3-3 test equipment chose the direct voltage measurement method to measure the voltage change.

The flicker meter was originally designed to be used as a power quality measuring device using direct voltage measurement to measure the voltage drop on the mains network in order to calculate the flicker value.

The direct voltage measurement across a reference impedance put strict requirements on the test equipment. The basis for flicker evaluation is the voltage change waveform at the terminals of the equipment under test. In other words, it is the difference ΔU of any two successive values of the phase-to-neutral voltages U(t1) and U(t2):

$$\Delta U = U(t1) - U(t2) \qquad (1)$$

where

U(t1) = voltage at the terminals of the test object with no current flowing and

U(t2) = voltage at the terminals of the test object when current is flowing.

The RMS values U(t1), U(t2) of the voltage shall be measured or calcu-

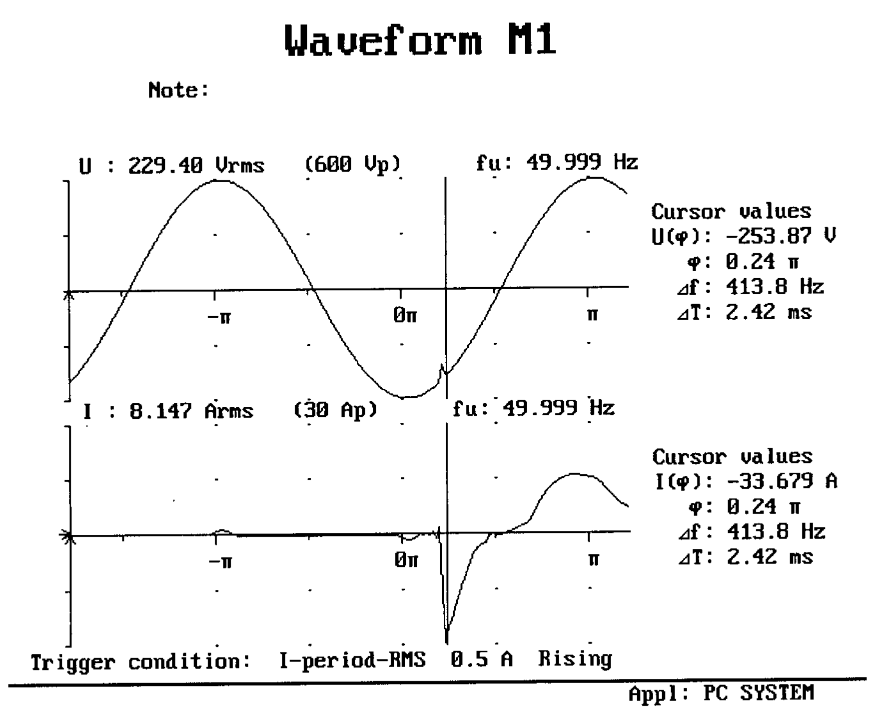

Figure 6. *Inrush Current from Sleep Mode to Operating Mode.*

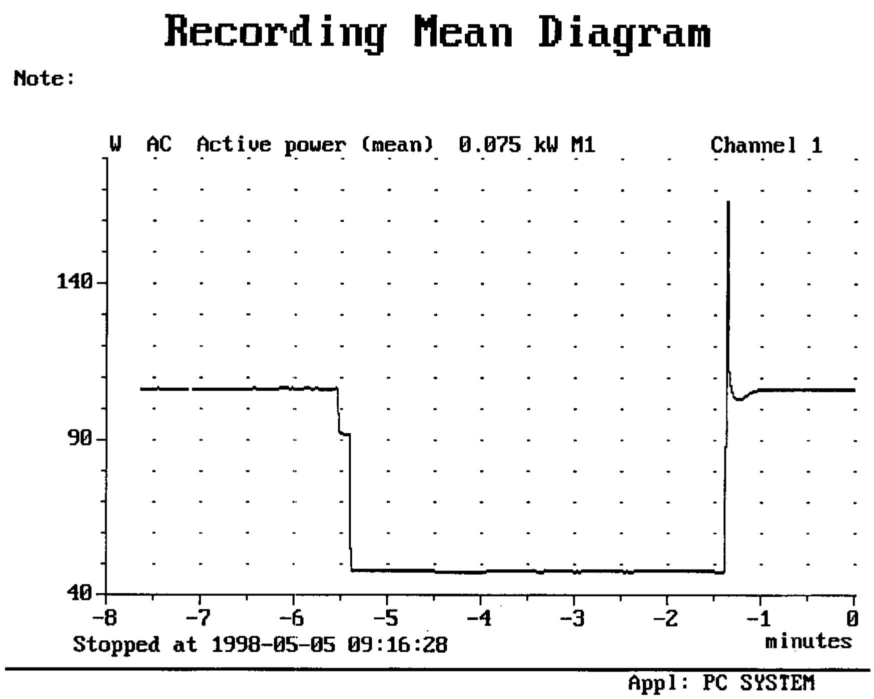

***Figure** 7. Single-stage Energy Saving Mode.*

lated. The voltage change ΔU is due to the change of the voltage drop across the complex reference impedance Z, caused by the complex fundamental input current change, ΔI, of the equipment under test.

Measuring the voltage drop with direct voltage measurements has a basic disadvantage in the fact that it only uses a very small part of the voltage measurement range. With a voltage setting of 230 V, the voltage range must be at least around 350 V, but could be as high as 600 V, depending on the range limits of the test equipment (Figure 9).

The smallest voltage drop that has to be measured is around 0.3% of the nominal voltage. Assume this voltage drop to be measured with an uncertainty of less than 4% (half of the total error than is specified). This leads to a required measurement uncertainty better than 0.006% of the voltage range for instruments using this method.

Analyzers are available which use *power measurements* as a basis for the voltage drop calculation. The corresponding typical current range is 30 A and a current variation of 1.7 A to produce 0.3% voltage drop. The required uncertainty is around 0.23% of the current range.

The whole integrated test system can have a reference impedance of $Z = 0.4\ \Omega + j0.25\ \Omega$.

Most solution vendors offer a physical reference impedance specified according to the EN 61000-3-3 standard and state a zero output impedance for the source using remote sensing at the terminals of the equipment under test. This means that the source impedance is compensated by controlling the output voltage of the AC source. For steady-state loads, this is no problem. However, all AC sources have an output impedance that varies with frequency and the size of the load variation. There is a static component in the impedance variation that corresponds to load regulation. There is also a complex dynamic component in the output impedance that depends on the frequency response of the source voltage regulation for rapid load changes.

Since our test object is a typical Class D object in standby mode and operating mode, the PC system generates voltage harmonics and the source impedance will increase because of the higher order harmonics. In this case, the total output impedance in the test systems will dif-

SUMMARY OF ASSESSMENT METHODS

Type of voltage fluctuation waveform	Current: total harmonic distortion less than 5%	Current: total harmonic distortion 5% or more
a) or b) or c)	**Direct flicker measurements** Flickermeter or	**Direct flicker measurements** Flickermeter or
	Voltage measurements Calculate $\Delta U/U$ from design characteristics or from direct measurements (peak or RMS values or	**Voltage measurements** Calculate Δ/U from design characteristics or from direct measurements of half wave RMS values
	Current measurements Calculate $\Delta U/U$ from measurements of I (peak or RMS values) and cos Φ or	or
	Power measurements Calculate $\Delta U/U$ from measurements of Ip and Iq	**Power measurements** Calculate Δ/U from measurements of Ip and Iq

***Table 1.** Assessment of Voltage Fluctuations and Flicker Referring to Section 4.2 in EN 61000-3-3.*

Extreme Flicker-I M1

Note:

Numerical Reference Impedance
U: 230.0 V I: 0.88 A f: 49.998 Hz PF: 0.528

EVALUATION:

Type of observation period		Short	Long	Limit
Observation time	Tp :	8	8 min	
Maximum relative voltage change	dmax:		0.71 %	4
Max rel steady state voltage change	dc :		0.05 %	3
Duration of d(t) > 3 %	t :		0.00 s	0.2
Short term flicker severity	Pst :		0.12	1.00
Long term flicker severity	Plt :	---	0.12	---

Based on 1 (1) short term cycles

PASSED

Measurement completed

Appl: PC SYSTEM

Figure 8. When the PC System Is Ramped Down to Sleep Mode in a Repetitive Way with Three Switch-ons in 8 Minutes, the Unit Is Likely to Flicker.

fer from the specified reference impedance and may not meet the requirements of the standard (Figure 10).

An output impedance from the source corresponding to 10% of the reference impedance, Z, will cause a direct proportional error of 10% in the voltage drop measurement when using direct voltage measurements.

When using power measurements, a voltage drop in the supply voltage will only result in a proportional current deviation. The resulting error in the voltage drop calculation will become 0.12% instead of 4% for the standard method. This means that it is difficult to design a test system for direct voltage measurements that handles worst-case loads within the limits that are specified in the EN 61000-3-3 standard.

A great problem for test houses and solution vendors is that the EN 61000-3-3 standard does not define any method for system verification, nor is a method given for calibrating the complete test. The EN 61000-3-3 standard refers to the EN 61000-4-15 standard where calibration of the flickermeter is defined. However, this is only a partial calibration for the test system.

As pointed out, one of the most critical aspects of accurate flicker measurements is the accuracy of the total output impedance, and to calibrate that, a known varying load is needed.

Tough Requirements, January 2001

Recently, a proposal that postponed the DOW (Date of Withdrawal) date for a wide amount of basic standards, as well as product standards that will affect the EMC testing requirements for products sold in the European market, was published in the *Official Journal of the European Community* (OJEC). The reason seems to stem from a disagreement between the commission and CENELEC on how to handle the certification clause and how to replace an old standard with a new one. Until now, the maximum time between the DOP (Date of Publishing), and DOW for a standard was set to 5 years. The certification clause permitted a smooth initiation of a new standard where products could be tested to the old standard, e.g., EN 60555, a fixed period after the DOW date. With the decision from CENELEC, the certification clause is taken away. In practice, this means that the only mandatory requirement for products now sold in the EC is to test products for household and similar use according to EN 60555-2 and EN 60555-3. It is also possible to test these products against the EN 61000-3-2 and EN 61000-3-3 standards. As a result, there will be no need for the additional testing that is required by January 1, 2001. It now also seems likely that the remaining issues for professional products with a power above 1000 W will be resolved well in time before the new date.

For industrial or professional products, the new date means that the industry is given a prolonged period to adapt new products to the EN 61000-3-2 and EN 61000-3-3 standards. Note, however, that even old products already on the market have to meet the new standards and there is no transition time.

With this background, the industry should start to adapt its existing and new products to the new requirements now to ensure that cost-effective solutions are implemented in time.

Summary

A wide range of products will be influenced by the harmonics and flicker standards in the near future.

Both existing and new products have to comply with the harmonics and flicker standards no later than Janu-

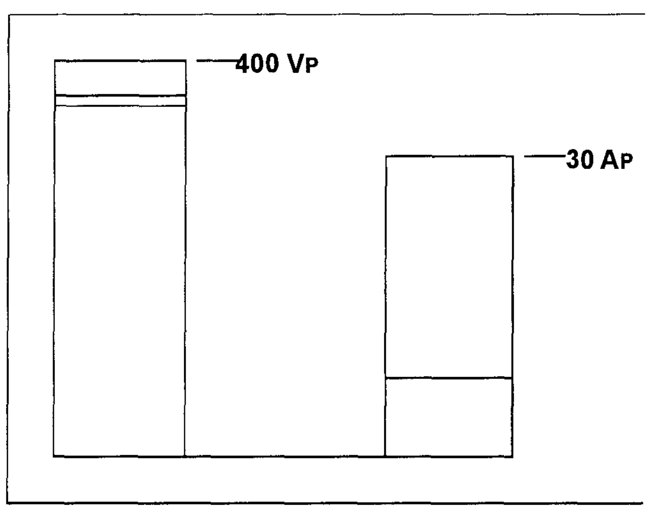

Figure 9. The Required Accuracy of the Test Equipment is 0.006% for Direct Voltage Measurement to Measure a 0.3% Voltage Change Within the Standard Limits for dmax. 0.23% Accuracy is Needed Using Power Measurements.

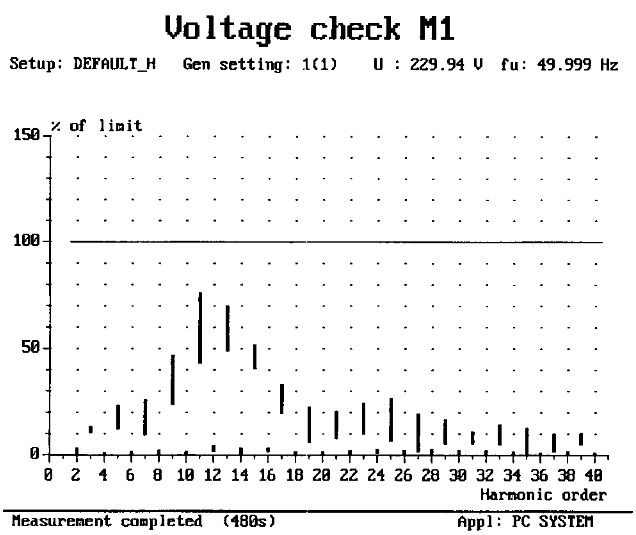

Figure 10. *AC Source Voltage Harmonics Relative to the Limit for AC Source Requirements During the Single-stage Energy-saving Mode.*

ary 1, 2001 to be sold in the European market.

There are still some unresolved questions in both the harmonics and the flicker standards. To be on the safe side, it is advisable that all manufacturers soon become aware of how this could influence both existing and new products.

In many cases, it is clear that units which individually will meet the requirements to be CE-marked still may fail as a system. Typical examples of this are computer systems and even a simple PC system.

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