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TECHNICAL REPORT

colour inside

Electromagnetic compatibility (EMC) –
Part 4-37: Testing and measurement techniques – Calibration and verification protocol for harmonic emission compliance test systems

IEC TR 61000-4-37:2016-01(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-37: Testing and measurement techniques – Calibration and verification protocol for harmonic emission compliance test systems

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 61000-4-37, which is a Technical Report, has been prepared by subcommittee 77A: EMC-Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

This publication contains attached files in the form of an xls document and a user guide. These files are intended to be used as a complement and do not form an integral part of the standard. They may be updated from time to time.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77A/907/DTR	77A/919/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The “colour inside” logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

Harmonic current analysis systems are used to measure emissions from equipment that is tested in accordance with various standards. The IEC (International Electrotechnical Commission) adopted measurement and evaluation techniques that are specified in IEC 61000-4-7, but limits, limit comparisons, certain exclusions, and test conditions for a variety of products are specified in IEC 61000-3-2 (for 16 A per phase and below) and IEC 61000–3-12 (from 16 A to 75 A per phase). This Technical Report provides test patterns for IEC 61000-3-2, but will be expanded in future editions to also include specific tests per IEC 61000-3-12 for currents above 16 A per phase. The methodology described in this Technical Report can also be expanded to provide fluctuating harmonics, along with inter-harmonics.

This Technical Report is neither intended as a type test nor as an exhaustive test of all required analyzer capabilities according to IEC 61000-3-2, IEC 61000-3-12, and IEC 61000-4-7. The primary objective is to verify on a periodic basis (for example for renewal of accreditation) that the harmonic analysis test system, consisting of a previously type tested analyzer and a suitable power source, performs correctly, and the performance of the system is not adversely affected by the system integration, nor has changed over a period of time.

The purpose of the harmonic current analysis systems is to evaluate harmonic current emissions, the power factor, and other parameters, in accordance with the requirements of the above mentioned standards. In addition to the harmonics measurement, the harmonic analyzer may have automatic limit evaluation software or firmware, data storage, additional analysis capabilities, and report generation capabilities that facilitate the process of certifying the tested products according to IEC 61000-3-2 and/or IEC 61000-3-12.

The primary purpose of this test, verification and calibration procedure in this Technical Report, is to establish methods that may be used to verify that a given harmonic analysis system measures and evaluates common harmonic current emission patterns in accordance with the requirements of the standards, and thus allows the user to perform a correct pass/fail analysis of the tested product. Additional capabilities of the analyzer or test system may also be tested using some of the tests described in this Technical Report.

The tests as summarized in Clause 4 may also be used to improve or optimize the accuracy of the harmonics measurement system. This can be done either via the r.m.s. current – if so required by using external reference equipment, and/or by adjusting the frequency response – provided the harmonics analysis system has either hardware or software adjustments to permit the parameter accuracies to be optimized.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-37: Testing and measurement techniques – Calibration and verification protocol for harmonic emission compliance test systems

1 Scope

This part of IEC 61000, which is a Technical Report, outlines a typical test procedure for harmonic analysis in systems comprising

- tests apparatus designed to comply with IEC 61000-4-7, and
- products designed to comply with IEC 61000-3-2 and/or IEC 61000-3-12.

The test procedure is intended to provide a systematic guidance suitable for use by manufacturers, end users, independent test laboratories and other bodies, for the purpose of determining the applicable compliance status within a wide range of harmonic current emissions.

The test procedure is derived from conditions observed in actual product testing and simulates closely conditions that can reasonably be expected.

The accuracy of harmonic analyzers and complete tests systems having adjustments or procedures, either hardware or software-based, may be optimized using external reference equipment of sufficient accuracy and the methodology in this Technical Report.

This Technical Report is not intended as a replacement for type testing of harmonic analyzers, nor does it check all of the parameters specified in IEC 61000-4-7, IEC 61000-3-2, and IEC 61000-3-12.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61000-3-2:2014, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-12, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase*

IEC 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*
IEC 61000-4-7:2002/AMD1:2008

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 General

Many products that are to be tested per IEC 61000-3-2 or IEC 61000-3-12 exhibit what is known as steady state or quasi stationary powers and harmonic current emissions. To evaluate whether such products meet the requirements set forth in IEC 61000-3-2 or IEC 61000-3-12, a variety of simple analyzers could be used. Thus, the analyzer used for these simple tests need not meet all the tests described in this Technical Report. For analyzers that are to be used in general purpose testing laboratories, or that are to be used to evaluate products exhibiting fluctuating harmonics, it is recommended to meet all of the applicable requirements set forth in this report. The test procedures are therefore defined in increasing order of complexity, allowing the user to just select the most basic tests for simple harmonic current emissions analysis, or perform a more extensive set of evaluations. Furthermore, the requirements of both IEC 61000-3-2 and IEC 61000-3-12 have been considered.

Harmonic analysis systems generally include a dedicated AC power source, although analysis may be performed using the mains voltage under certain conditions. Even though this Technical Report is not intended as an exhaustive test for AC power sources used in IEC compliance test systems, it verifies the suitability of such sources per the requirements specified in IEC 61000-3-2 and IEC 61000-3-12. The proposed tests are valid for harmonic current measurements at 100 V, 120 V, 220 V, and 230 V AC line-neutral at 50 Hz and 60 Hz, but are primarily aimed at 230 V/50 Hz systems.

Additional tests, specific for IEC 61000-3-12, may be defined in a future edition of this Technical Report.

Furthermore, this Technical Report does not have provisions to test system accuracies for all of the evaluation methods used in the Japanese edition of successive IEC 61000-3-2 versions, although it largely supports the requirements of JIS C 61000-3-2. This Technical Report does not cover harmonic emission tests where a series line impedance network would be required, such as specified in Figure 1-1 and Figure 1-1A of JIS C 61000-3-2:2011. As shown in various papers and actual tests, the use of a series line impedance, as specified in earlier editions of the Japanese standard JIS C 61000-3-2, can produce complex and unpredictable results, and thus no efforts are made to develop a test procedure that includes such a series impedance. JIS C 61000-3-2 allows harmonics tests without the use of a line impedance network, hence the procedure in this Technical Report is applicable to this type of tests per JIS C 61000-3-2.

The procedure in this Technical Report is intended to be compatible with related standards, in particular any safety requirements set forth by listing organizations or measurement standards of the International Electrotechnical Commission (IEC). Such safety requirements specified by the IEC or other parties may be different than criteria defined in this report. Therefore, meeting the criteria defined herein should not be construed as a waiver of any other relevant performance or safety requirements.

In general, the procedures and methodologies specified in ISO/IEC 17025 should be followed to verify that the test and verification signals, measurement procedures, external reference equipment and evaluation methods specified in this Technical Report, are produced with sufficient accuracy to meet the stated goal of evaluating the harmonics analyzer or analysis system.

If the results of a test procedure on a given harmonic test system deviate from the expected results given in this Technical Report, the cause for the deviation needs to be identified, and the system needs to be corrected. This may require external equipment and/or calibration of individual system components.

4 Objectives of harmonic analysis test procedures

The primary objective of the test procedures is to assure that analyzers and compliance test systems that meet the requirements set forth in this Technical Report, produce results that lead to correct and reproducible pass/fail evaluations, when testing products in accordance with IEC 61000-3-2 and/or IEC 61000-3-12. Thus, it is intended that various test systems that pass the tests described in this Technical Report will produce identical test results, that is within specified tolerances, when evaluating the same equipment (unit) under test (EUT or UUT) under identical or near identical environmental and test conditions.

To achieve this primary objective, not only do certain accuracy requirements need to be met, but the harmonic analysis system also needs to be suitable to make certain logical decisions and evaluations. Examples of such logical decisions include the evaluation of power limits (Class D from 75 W to 600 W and Class C), partial odd harmonic current (POHC) calculation, partial weighted harmonic current (PWHC) calculation, determination of the phase angle of H_5, whether or not a preferential value for the phase of H_5 exists, and whether or not current flow is present at certain phase angles (self-ballasted lamps), etc. Furthermore, the system has to be able to perform additional limit calculations, such as permitting Class A products to have individual harmonic emissions up to 200 % provided that the average emissions are less than 90 % of the limits, as specified in IEC 61000-3-2.

In general therefore, this Technical Report seeks to increase the uniformity of measurements and evaluation methods made by various implementations of the harmonic analysis systems. In more detail, the procedure uses the following methodology to achieve the above objectives:

Define the expected measurement, including tolerances, and pass/fail result for a given input signal:

1) Test how well the harmonic analyzer/system performs the various measurements and analysis against the specifications set forth in IEC 61000-4-7.
2) Provide common, reproducible methods of testing so that tests can be repeated at any time with any harmonic analysis system designed to meet IEC 61000-4-7, and designed to evaluate products in accordance with IEC 61000-3-2 and IEC 61000-3-12.
3) Provide test procedures for distribution to manufacturers and integrators of harmonic analysis systems, so that they may evaluate their products prior to placing them on the market.

5 Performance criteria

IEC 61000-4-7 defines the harmonic analyzer in detail, and provides certain accuracy requirements. It has been shown, however, that different harmonic analysis test system implementations – all claiming to meet the accuracies defined in IEC 61000-4-7 – can still disagree significantly in some actual measurements. It has been proven that the AC test source and interconnecting wires/impedances can substantially affect the measured harmonics, but problems with analyzer implementations, and differences in interpretation of requirements in the standards IEC 61000-3-2 and IEC 61000-3-12, have been found as well.

The individual steps of the test procedure in this Technical Report are intended therefore to provide a set of tests to ensure that the analyzer, AC power source, and overall system implementation are correct and produce the desired results. Whereas it would be possible to define even more demanding tests, the set of 12 different tests suffice to verify overall system suitability for harmonic analysis. In fact, a system may even fail to meet the requirements of tests no. 11 and 12, and still be suitable for most product tests according to IEC 61000-3-2.

The performance criteria can be separated into 3 main categories. The first category is aimed at verifying the harmonic analyzer in accordance with the accuracy and implementation requirements of IEC 61000-4-7. The second category is a system test, intended for use with complete test systems, which therefore includes an evaluation of the AC power source and system integration. The last category is intended to verify the evaluation methods, including the proper determination of limits, and decision logic for determining test classes and pass/fail assessments as specified in IEC 61000-3-2 and IEC 61000-3-12.

For in-house test systems with a limited scope of use, only a subset of the test can be used. For example, if a particular manufacturer's EMC test facility only needs to test per Class A and Class D, it would not be necessary to evaluate the system per Class B or Class C of IEC 61000-3-2.

Some compliance test systems have power sources with limited output current capability. Tests that exceed the power output capability can be skipped, provided this is noted in the test report. The following Table 1 provides a summary of the tests. The test tolerances in Table 1 for individual harmonics are set at approximately a 1/3rd of the estimated uncertainties in IEC 61000-3-2:2014, 6.2.3.2. This provides a sufficient test uncertainty ratio.

NOTE This uncertainty ratio is sufficient for the tests per this Technical Report. For calibration purposes of individual system components, smaller uncertainties and/or external reference equipment might be necessary.

Although the basic methodology described in this document may provide sufficient accuracy for the evaluation of current signals in the time domain, verification and calibration test procedures for time domain signals represent a totally different set of requirements than those currently provided for in IEC 61000-4-7. At this time, there are no defined accuracy and repeatability criteria in either IEC 61000-4-7 or IEC 61000-3-2 to determine whether or not a tested instrument or system is within the desired tolerances. Therefore, evaluation and analysis of current signals in the time domain are deferred to a future version of this Technical Report.

Table 1 – Summary of tests to verify/calibrate harmonics analysis systems

IEC 61000-3-2 Test class and result	Test no.	Description of load settings and current	Required result	Comments
Initial system test with a linear load, producing a sinusoidal current at approximately 8 A.	0	Linear load of approximately 28 Ω resulting in a current of 8,2 A (r.m.s)	PASS	This test verifies that the AC source voltage quality is acceptable when a linear load is applied. It is also used to verify the basic current and voltage measurement accuracy. The user may perform this test at a lower current for smaller power sources, or add a test at higher currents for bigger systems.
General Class A test at ~550 W passing the Class A limits.	1	Phase controlled load of ~80 Ω with conduction from 45° to 135° resulting in 2,4 A to 2,6 A r.m.s. and harmonics below Class A limits, with the highest harmonics being 80 % to 86 % of the limits. The user may also verify that the power source distortion is within limits.	PASS	This is a relatively simple general and functional test per Class A. Both Class I and Class II instruments per IEC 61000-4-7 should yield results well within the tolerance per Table 1 of IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, and well within the tolerances per IEC 61000-3-2:2014, 6.2.3.
Class A test at ~700 W and with odd harmonics from order H11 failing the Class A limits	2	Phase controlled load of 60 Ω to 64 Ω with conduction from 45° to 135° resulting in 3,2 A to 3,5 A (r.m.s.) and odd harmonics from H15 exceeding Class A limits. Odd harmonics 15, 19, 23, 27, 31, 35, 39 should be from 105 % to 115 % of the limits, while other odd harmonics > 15 are close to or above the limits, depending on the exact load. Note that this test can be repeated for Class B limits, with a "PASS" result. This test can also be used to verify that the power source voltage distortion meets the requirements per IEC 61000-3-2, while supplying power for a product that fails Class A limits.	FAIL	General and functional test using Class A limits. Power is suitable for all harmonics test systems that accommodate up to ~700 W. This test may also be used to calibrate the applicable current range of the IEC 61000-4-7 instrument – such as 5 A r.m.s., and to verify and/or calibrate the frequency response of the instrument, as the harmonics up to 2 kHz have significant amplitudes.
Class A test at ~3 100 W failing H15, H17, H19 having values between 120 % to 130 % of limits, and H21, H35, H37, H39 above 100 % of the limits	3a	Phase controlled load of ~17 Ω with conduction angle from 4° to 166°, producing 13,5 A r.m.s.	FAIL	This tests the dynamic range and accuracy of the harmonics analyzer with higher order harmonic amplitudes < 2 % of the overall current. The r.m.s. current may also be used to calibrate the applicable range(s) of the harmonics analyzer.
Class B test at ~3 100 W with settings identical to above test 3a	3b	Same load as for above test 3a	PASS	This test verifies that Class B limits are evaluated properly. The r.m.s. current may also be used to calibrate the applicable range of the harmonics analyzer.
Class B test at ~1 000 W failing the Class B limits	4	Phase controlled load of 41 Ω with conduction angle from 60° to 155°, producing 4,7 A to 5,0 A r.m.s.	FAIL	This test produces harmonics that fail harmonic order H13, H17, H21, H25, etc., that are above the limits for test Class B.

IEC 61000-3-2 Test class and result	Test no.	Description of load settings and current	Required result	Comments
Class C test at ~160 W to 640 W with harmonics that just pass the limits	5	Phase controlled load of ~80 Ω with conduction from 7° to 148° producing 2,6 A to 2,8 A r.m.s. For lower power systems, this test may be conducted with a load that results in lower current, for example 150 Ω to 350 Ω. For example, 320 Ω results in 0,7 A r.m.s. and 160 W. The limit evaluation is not changed, as Class C has proportional limits.	PASS	This test produces harmonics that just pass the limits for orders H7, H9, H11, and active power with a PF of 0,981. The test verifies proper calculation and evaluation of Class C limits. It may also be used to adjust and/or calibrate differential phase delay between voltage and current channels of power analyzers utilizing (external) CTs.
Class C test at ~520 W with harmonics that fail the limits	6	Phase controlled load of ~80 Ω with conduction from 54° to 160° producing 2,5 A to 2,7 A r.m.s. See also the comments for test 5 above.	FAIL	This test produces harmonics that fail the limits for orders H3, H5, H9, H11, H13, H15, H19, H21, and active power with a PF of 0,918. This test may also be used to verify that the power source meets the voltage distortion requirements.
Class D test at ~540 W with harmonics that pass the limits	7	Phase controlled load of ~80 Ω with conduction from 45° to 135° producing 2,4 A to 2,6 A r.m.s. This test can also be used to verify that the power source voltage distortion meets the requirements per IEC 61000-3-2, while supplying power for a product that meets Class D limits.	PASS	IEC 61000-3-2 Class D evaluation with some odd harmonics from H11 to H39 in the order of 90 % to 95 % of the limits. This test also allows the verification of Class D limit calculations as the limits are proportional to power, as well as the verification of parameters such as PF, CF, THD and POHC.
Class D test at the mid-point of the 75 W to 600 W range, i.e. ~380 W with harmonics that fail the limits	8	Phase controlled load of ~80 Ω with conduction from 45° to 106° producing 2,1 A to 2,3 A r.m.s. This test may be conducted with a load that results in lower current, for example 150 Ω to 350 Ω. For example, 320 Ω will result in 0,55 A r.m.s. and ~96 W. The limit evaluation is not changed.	FAIL	IEC 61000-3-2 Class D evaluation with odd order harmonics from H9 on up that are up to about 200 % of the limits. This test also allows the verification of Class D limit calculations as the limits are proportional to power, as well as the verification of parameters such as PF, CF, THD and POHC.
Class D test at ~500 W with higher order odd harmonics that pass the POHC limit	9	Phase controlled load of ~80 Ω with conduction from 20° to 122° producing 2,4 A to 2,6 A r.m.s. This test may also be done with other loads, such as 320 Ω resulting in 0,65 A and 135 W.	PASS	IEC 61000-3-2 Class D evaluation with odd order harmonics H23 and H37 that fail the 100 % limit, but the overall test passes because of the POHC allowance.
Class A test at ~650 W with higher order odd harmonics that fail the POHC limit	10	Phase controlled load of ~80 Ω with conduction from 55° to 59° and linear load of ~80 Ω producing 3 A r.m.s.	FAIL	IEC 61000-3-2 Class A evaluation, using a linear load and superimposed controlled load, causing odd order harmonics from H25 to H39 to exceed 100 % of the limits but remain below 150 %. The POHC evaluation results in a failed test result. This test can be used to verify the instrument calibration and dynamic range.
Class A test at ~700 W and 11 A peak with higher order odd harmonics from H13 that fail the limit	11	Phase controlled load of 40 Ω to 44 Ω with conduction from 66° to 72° and linear load of 80 Ω to 85 Ω producing ~3,5 A r.m.s. and ~11,5 A-peak, and a power of 735 W.	FAIL	This test is mainly to verify the dynamic range of both the power source and the analyzer, and to test the analyzer for proper ranging. This test can be used to check the bandwidth and calibration of the harmonic analysis system, with currents that include a substantial linear current, and higher order harmonics.

IEC 61000-3-2 Test class and result	Test no.	Description of load settings and current	Required result	Comments
Overall system test at 1 480 W, with pulse like peak current of 30 A and harmonics from H5 to H39 that fail the limit.	12	Phase controlled load of ~32 Ω with conduction from 66° to 72° and linear load of 40 Ω to 43 Ω producing 6,4 A (r.m.s.) and ~17,5 A (peak), and ~1 400 W.	FAIL	This test is an "aggravated version" of test no. 11 and is used to verify the dynamic range of both the power source and the analyzer, and to test the analyzer for proper ranging. This test is also a general system stability and analyzer dynamic response test.
NOTE All tests per the table above are defined for nominal 230 V ±0,23 V.				

6 General test guidelines

This Technical Report is intended to be used for the verification or calibration (see 9.2 n)) of harmonic test systems that are obtained with the cooperation of the manufacturer or the user of the test system, in order to ensure that the analyzer or system is being tested with the intended use of the device.

To assist the user in correctly applying the analyzer or test system, the testing authority should obtain detailed accuracy specifications for the analyzer or test system, in accordance with its intended use. That is, the user or testing authority should have enough information to assure that the analyzer or system is used within its voltage, current, and power range(s), and within the scope of its intended testing capabilities.

7 Essential information

Essential information should be marked on the device and supplementary information provided with the analyzer or test system package. The following list is provided as an example of the information requirements:

a) manufacturer's name or trade mark;

b) product name(s), and/or model number(s), and serial number(s);

c) mains frequency operating range(s);

d) limits for voltage and current measurement inputs (absolute maxima for nominal input ranges);

e) AC voltage source requirements (if the AC source is part of the evaluation);

f) AC voltage source output specifications (if the AC source is part of the evaluation);

g) compliance with applicable standards (e.g. IEC 61000-4-7, IEC 61000-3-2, IEC 61000-3-12);

h) analyzer accuracy specifications for voltage, current, power, PF, harmonics;

i) analyzer accuracy for I_5 phase angle and inter-harmonics grouping if supported by the instrument;

j) AC power source accuracy and stability specifications (if the AC source is part of the evaluation);

k) software and/or firmware version of the analyzer and/or power source and other system components;

l) installation and usage instructions.

8 Test equipment and accuracy

Different types of test equipment are required for the individual tests given in this report. The test equipment accuracy should be at least a factor of three better than the accuracy specifications given in the individual performance tests. The responsibility to verify this accuracy rests with the testing authority, but the methods, procedures, and general and management requirements specified in ISO/IEC 17025 should be followed. The recommended performance specifications for external reference equipment, as given in Clause A.5 of this document provide a margin of at least 3:1 versus estimated uncertainties according to IEC 61000-3-2:2014, 6.2.3.2.

NOTE 1 This uncertainty ratio is sufficient for the tests per this Technical Report. For calibration purposes of individual system components, smaller uncertainties and/or external reference equipment might be necessary. See 9.2 n).

In principle, all test patterns can be verified with readily available high accuracy digital voltmeters, current shunts and digital oscilloscopes, or data acquisition systems with sufficient resolution and memory. Annex A provides an informative set of guidelines for selecting appropriate test equipment to verify that the intended test patterns are indeed present.

A suitable method to generate the desired test patterns is provided as Annex A to this report, but the testing authority may use different methods to generate the required voltage, current, and harmonics test patterns, provided such methods are accompanied by analysis and/or measurements, following the requirements of ISO/IEC 17025, that prove the suitability of such alternative testing patterns and methods.

Furthermore, the test patterns described in this Technical Report and in Annex A were defined with the specific intent to verify complete systems for harmonic emission compliance test. For the purpose of verifying just the harmonic analyzer, including type testing, alternative harmonic test patterns and testing equipment suites have already been developed, supported by detailed analysis and verification, and have been successfully used. Such calibrations are available from national metrology institutes and ISO/IEC 17025-accredited calibration laboratories worldwide.

The methods in this report complement the verifying of individual system components, such as the harmonic analyzer, with the verifying of the entire system. Laboratory comparisons have shown that the AC power source and system integration can have significant impact on the result for IEC 61000-3-2 and IEC 61000-3-12 testing.

Thus testing just the harmonic analyzer, or system components, to be compliant with the applicable standards, is no guarantee that correct pass/fail evaluations according to IEC 61000-3-2 or IEC 61000-3-12 can be performed when the certified analyzer and other system components are integrated into a complete system with an untested AC power source. Generally, the tests in this Technical Report are designed to reveal any discrepancy in the harmonics test system, but the tests are not intended as a complete type test of every system component. The test patterns are not necessarily intended for type testing, but could be used to test specific system functions.

There are also more demanding test patterns possible, which would potentially cause harmonic current analysis to deviate by more than the tolerances specified in IEC 61000-4-7 and IEC 61000-3-2:2014, 6.2.3. Some examples include a test pattern with just a bridge rectifier followed by a resistive load with a large parallel capacitor, having very high relative current emissions. Such a load was used in round robin tests, which ultimately resulted in a more realistic repeatability specification in IEC 61000-3-2 and IEC 61000-3-12. This type of demanding pattern may result in the Class A harmonics limits of IEC 61000-3-2 to be exceeded significantly. There is no practical need for any compliance test system to measure very high harmonics emissions with good accuracy, as the tested product would have emissions for example at 4 times the applicable limits, and even deviations of ±25 % from the ideal values would be irrelevant as the product would still fail the limits of IEC 61000-3-2. Test no. 11 could conceivably be viewed as such a demanding test, and certainly no. 12 is very demanding. These tests therefore might show some larger deviations from the tested system, and they are mainly intended to establish the limitations of the compliance test system, and the power source in particular.

For the purpose of verifying a complete system, intended for compliance testing in accordance with IEC 61000-3-2 and/or IEC 61000-3-12, it is necessary to follow the procedures outlined in this report, and use a harmonic generation unit (HGU) or equivalent method to produce the specified current and loading patterns for the AC power source, as described in Annex A. If the tested harmonic analyzer or complete system has provisions for adjustments, or has software-defined adjustment routines, several of the specified current and loading patterns may be used to optimize the analyzer or system, for both overall measuring accuracy and frequency response up to 2 kHz.

NOTE 2 A test up to 9 kHz might be considered in a future version of this technical report, after the responsible working groups have agreed on emission limits in the range to 9 kHz.

The loading patterns for the AC power source are not intended to be an exhaustive test, and it may reasonably be expected that some deviations of harmonic analysis – especially for higher order harmonics – will be found when comparing systems with different types of power sources and analyzers. Such differences need to be within the recommended tolerances of this report, but – more importantly – should not affect the correct pass/fail decision of the system. The uncertainties estimated per IEC 61000-3-2 were established as a result of the deviations found in round robin tests in various countries. IEC 61000-3-2 specifies (1 % + 10 mA) for reproducibility (1 % of the average value of the total input current taken over the entire test observation period) when testing the same EUT on different test systems. If the verification method and EUT are closely specified, the user may opt for a closer tolerance. The tolerances recommended for this Technical Report are approximately 1/3rd of the estimated uncertainties in IEC 61000-3-2, thereby providing sufficient margin to prevent the deviations from leading to false PASS or false FAIL evaluations by systems tested per this Technical Report. If the harmonic current generation is sufficiently accurate an even higher ratio or margin can be obtained.

NOTE 3 IEC 61000-3-2 states that differences in results are usually less than the estimated uncertainty, but in some cases higher values can occur.

9 Detailed test procedures

9.1 General

Clause 9 provides the rationale for each test, with details for implementation and execution.

9.2 Procedures common to all tests

The following list provides procedures common to all tests:

a) Connect the harmonic analyzer, AC power source, and harmonic generator unit as shown in Figure A.1.
b) Make sure all input power requirements according to the manufacturer's specifications are met.
c) Record software and firmware versions of all system building blocks.
d) Perform the procedures specified by the system manufacturer to ensure that the system performance is in accordance with the manufacturer's specifications.
e) Adjust the analyzer measurement settings, such as for the selected test voltage range (e.g. 100/120 V, 230 V, 50/60 Hz) and the configuration for single or 3-phase tests, as required for the specific test system. Note that the currents and spectra are frequency independent, i.e. tests may be performed at either 50 Hz or 60 Hz.
f) Configure the AC power source for the specific test.
g) Configure the harmonics generator/load unit to produce the desired test pattern.

h) Perform the test and compare the obtained data with the expected results, as specified in the tables. If the test reveals errors beyond the tolerances specified in this Technical Report, and the analyzer or test system have hardware or software adjustments, several of the tests may be used to make the adjustments needed to minimize the errors and thus improve the overall accuracy and the frequency response. A subsequent test is then performed to document the improved results.

i) If the analyzer or system being verified is suitable for 3-phase testing, the tests below should be performed for every phase. The testing authority may use a single phase load and test each phase consecutively or use a 3-phase load and test all three phases simultaneously.

j) The harmonics simulation software (spreadsheet, see Clause 10) that is available for use with this Technical Report, may be used to compute the expected harmonic spectrum for loads that deviate slightly from the specified values in the tables.

k) The phase angles for current conduction and current cut-off need to be set with an accuracy of ±0,2° or better, in order to have harmonic current uncertainties less than (0,3 % + 5 mA). Loads can vary, and variations of ±1 % can easily be accommodated, and harmonic currents adjusted proportionally. Annex B provides detailed error analysis for variations in phase angles and/or loads, and Tables 2 and 3 illustrate the difference of a 1 % load change. Even though this is a POHC test at almost 3 times the limit, care is needed to minimize phase errors for this test.

NOTE For the dynamic range tests no. 11, a stop phase error of +0,2° causes an error of ~20 mA for several of the lower order harmonics, thereby exceeding the (0,3 % +5 mA) above, which computes to 15 mA for this test.

l) In general, the tolerances specified for all tests suffice for the purpose of testing according to IEC 61000-3-2. There are many analyzers available with specifications that far exceed the required accuracy for measuring voltages, current, active power and power factor according to IEC 61000-3-2. The user of this Technical Report should always consider what uncertainties the reference equipment has before making any adjustments to the analyzer and/or the power source. If measured parameters deviate from the desired values, it is of the utmost importance to determine the cause for these deviations. Any adjustment made to either the analyzer, power source, impedance box, or system integration aspects, can invalidate prior calibrations.

m) In the illustrations for each test, the harmonic emissions that fail the 100 % limit of the test class are coloured red.

n) If the reference equipment, such as the test setup described in Annex A, is traceably calibrated for all of the quantities specified in this Technical Report, any of the tests no. 0 to 9 can be used for system calibration. Unless the system being calibrated is intended for a specific test class per IEC 61000-3-2, it is recommended that the user performs at least one test for each test class, A, B, C and D.

9.3 Test no. 0

Test no. 0 consists of applying a linear load. The recommended load current is ~8 A. This is just a basic functional test to verify voltages and currents, and to verify that the power source distortion is within permitted tolerances. If this test is used for the verification of the built-in harmonic voltage measurement of the analyzer, then an external instrument of sufficient resolution and accuracy needs to be used.

9.4 Test no. 1 – General Class A test at ~540 W, to verify overall accuracy and allow verification of the measuring ranges being used

9.4.1 Rationale

This test is to verify that the instrument can measure harmonic current and r.m.s. voltage according to IEC 61000-4-7, with the required accuracy in the range(s) used for this test. Many consumer products have powers around the 500 W range, and fall into Class A, so this is an initial test to verify proper operation at this power.

9.4.2 Test procedure

The following list details the test procedure:

a) Follow the common procedures specified in 9.2.

b) Configure the AC power source for the correct frequency and voltage (i.e. 230 V, 50 Hz).

c) Use a suitable programmable load, such as the harmonics generation/load unit illustrated in Annex A to create a waveform as shown in Figure 1, with a conduction angle from 45° to 135°. The expected harmonics currents for a load of 80,0 Ω are specified in Table 2. If the load is not exactly 80,0 Ω adjust the expected spectrum proportionally (see Tables 2 and 3 as examples).

d) Verify that the measured values are within ±(0,3 % I_f + 5 mA), of the actually generated harmonic currents, and that the voltage distortion meets the requirements of IEC 61000-3-2:2014, Clause A.2.

e) Repeat steps c) and d) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

Figure 1 – Waveform and harmonics versus Class A limits for test 1

**Table 2 – Harmonics and data for test 1 –
General Class A with harmonics that pass the limits**

Linear load resistance / Ω	100 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	541,55
Apparent power / VA	598,55
Power factor	0,905
Current crest factor	1,563
Current THD / %	46,3
Partial odd harmonic current (POHC) / A	0,204
Current / A	2,602
Peak current / A	4,069
Start phase / °	45
Stop phase / °	135

Harmonic number	**Amplitude** / A	**Limit** / A	**Status**	**% of limit**
1	2,3546			
2	0,000 0	1,080	PASS	0
3	0,915 0	2,300	PASS	39,8
4	0,000 0	0,430	PASS	0
5	0,305 0	1,140	PASS	26,8
6	0,000 0	0,300	PASS	0
7	0,305 0	0,770	PASS	39,6
8	0,000 0	0,230	PASS	0
9	0,183 0	0,400	PASS	45,8
10	0,000 0	0,184	PASS	0
11	0,183 0	0,330	PASS	55,5
12	0,000 0	0,153	PASS	0
13	0,130 8	0,210	PASS	62,3
14	0,000 0	0,131	PASS	0
15	0,130 7	0,150	PASS	87,2
16	0,000 0	0,115	PASS	0
17	0,101 7	0,132	PASS	76,9
18	0,000 0	0,102	PASS	0
19	0,101 7	0,118	PASS	85,9
20	0,000 0	0,092	PASS	0
21	0,083 3	0,107	PASS	77,7
22	0,000 0	0,084	PASS	0
23	0,083 2	0,098	PASS	85,1
24	0,000 0	0,077	PASS	0
25	0,070 5	0,090	PASS	78,3
26	0,000 0	0,071	PASS	0
27	0,070 4	0,083	PASS	84,5
28	0,000 0	0,066	PASS	0
29	0,061 1	0,078	PASS	78,8
30	0,000 0	0,061	PASS	0
31	0,061 1	0,073	PASS	84,1
32	0,000 0	0,058	PASS	0
33	0,053 9	0,068	PASS	79,1
34	0,000 0	0,054	PASS	0
35	0,053 9	0,064	PASS	83,9
36	0,000 0	0,051	PASS	0
37	0,048 3	0,061	PASS	79,4
38	0,000 0	0,048	PASS	0
39	0,048 3	0,058	PASS	83,6
40	0,000 0	0,046	PASS	0

The data in Table 2 is computed for exactly 230,0 V and for an 80,0 Ω phase controlled load (45° to 135°). If the load is slightly different, the expected spectrum is adjusted accordingly (see Table 3 for 80,8 Ω). Except for the fundamental and the 3rd harmonic, all differences are within a few mA for the 80,8 Ω versus 80,0 Ω. Even for the 3rd harmonic, the difference is the expected 1 %, i.e. 9 mA. Differences in harmonic percentage versus limits are also less than 1 %. Thus, the expected harmonics are not very sensitive for load changes. Annex B details this further.

Table 3 – Spectrum of test 1 for 80,8 Ω

Harmonic number	Amplitude / A	Limit / A	Status	% of limit
1	2,331 3			
2	0,000 0	1,080	PASS	0
3	0,905 9	2,300	PASS	39,4
4	0,000 0	0,430	PASS	0
5	0,302 0	1,140	PASS	26,5
6	0,000 0	0,300	PASS	0
7	0,302 0	0,770	PASS	39,2
8	0,000 0	0,230	PASS	0
9	0,181 2	0,400	PASS	45,3
10	0,000 0	0,184	PASS	0
11	0,181 2	0,330	PASS	54,9
12	0,000 0	0,153	PASS	0
13	0,129 5	0,210	PASS	61,7
14	0,000 0	0,131	PASS	0
15	0,129 4	0,150	PASS	86,3
16	0,000 0	0,115	PASS	0
17	0,100 7	0,132	PASS	76,1
18	0,000 0	0,102	PASS	0
19	0,100 7	0,118	PASS	85,0
20	0,000 0	0,092	PASS	0
21	0,082 4	0,107	PASS	76,9
22	0,000 0	0,084	PASS	0
23	0,082 4	0,098	PASS	84,2
24	0,000 0	0,077	PASS	0
25	0,069 8	0,090	PASS	77,5
26	0,000 0	0,071	PASS	0
27	0,069 7	0,083	PASS	83,7
28	0,000 0	0,066	PASS	0
29	0,060 5	0,078	PASS	78,0
30	0,000 0	0,061	PASS	0
31	0,060 5	0,073	PASS	83,3
32	0,000 0	0,058	PASS	0
33	0,053 4	0,068	PASS	78,3
34	0,000 0	0,054	PASS	0
35	0,053 4	0,064	PASS	83,0
36	0,000 0	0,051	PASS	0
37	0,047 8	0,061	PASS	78,6
38	0,000 0	0,048	PASS	0
39	0,047 8	0,058	PASS	82,8
40	0,000 0	0,046	PASS	0

9.5 Test no. 2 – Class A test at ~700 W with harmonics failing the Class A limits

9.5.1 Rationale

This test is to verify that the instrument properly determines a Class A failure at approximately 700 W, for odd harmonics 15 to 39, and measures current and voltages with the required accuracy at this power.

9.5.2 Test procedure

The following list details the test procedure:

a) Follow the steps outlined in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify that they are within ±1 % of their calculated "ideal" values, and that the power source voltage distortion meets the requirements of IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A to create a waveform/spectrum as shown in Figure 2, with a conduction angle from 45° to 135°. The expected harmonics currents for a load of 61 Ω are specified in Table 4. If the load is not exactly 61 Ω adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3 % I_f +5 mA), of the actually generated harmonic currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

This test may be repeated with Class B limits, and should then result in a "PASS" because the harmonics are well below 150 % of Class A, i.e. well below Class B limits. The overall voltage, current, and the spectrum of this test 2 may also be used to calibrate or adjust the frequency response of the analyzer, if the unit has such adjustments available.

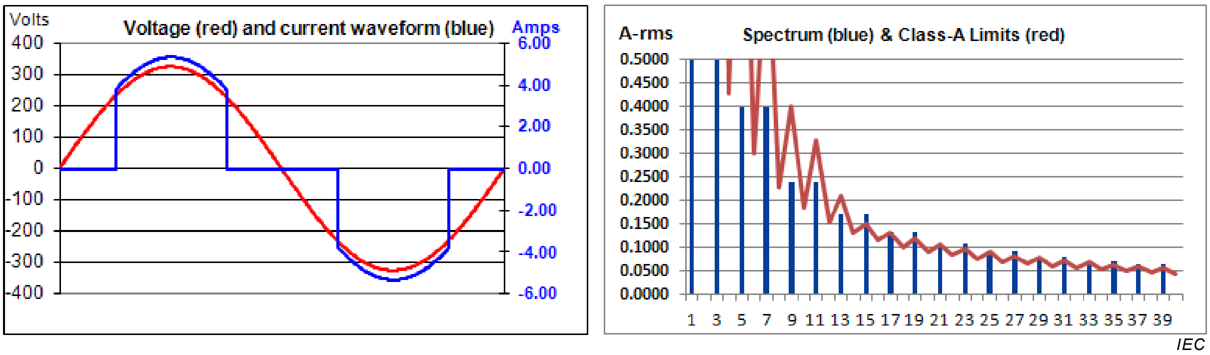


Figure 2 – Waveform and spectrum for test 2

Table 4 – Spectrum and data of test 2 for 61 Ω, at 45° to 135°

Calculated parameters	
Linear load resistance / Ω	100 000
Control load resistance / Ω	61,0
System voltage / V	230,00
Peak voltage / V	325,27
Power / W	710,06
Apparent power / VA	784,84
Power factor	0,905
Current crest factor	1,563
Current THD / %	46,3
Current THC / A	1,429
Partial odd harmonic current (POHC) / A	0,268
Current / A	3,412
Peak current / A	5,335
Start phase / °	45
Stop phase / °	135

Harmonic number	**Amplitude** / A
1	3,087 2
2	0,000 1
3	1,200 0
4	0,000 0
5	0,400 0
6	0,000 1
7	0,400 0
8	0,000 0
9	0,240 1
10	0,000 1
11	0,240 0
12	0,000 0
13	0,171 5
14	0,000 1
15	0,171 5
16	0,000 0
17	0,133 4
18	0,0001
19	0,133 4
20	0,000 0
21	0,109 2
22	0,000 1
23	0,109 2
24	0,000 0
25	0,092 4

Harmonic number	Amplitude / A
26	0,000 1
27	0,092 4
28	0,000 0
29	0,080 1
30	0,000 1
31	0,080 1
32	0,000 0
33	0,070 7
34	0,000 1
35	0,070 7
36	0,000 0
37	0,063 3
38	0,000 1
39	0,063 3
40	0,000 0

9.6 Test no. 3a – Class A at ~3 000 W with higher orders failing Class A limits

9.6.1 Rationale

This test is to verify that the power analyzer can measure higher order harmonics accurately in the presence of substantial fundamental currents, as well as measure power and the power factor (PF) with the required accuracy. If the analyzer or power source specifications are limited to currents less than those required for this test, this test may be operated at the maximum obtainable power for the AC power source. The waveform and spectrum are shown in Figure 3, which shows the Class A limits.

9.6.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify that they are within ± 1 % of their ideal values, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

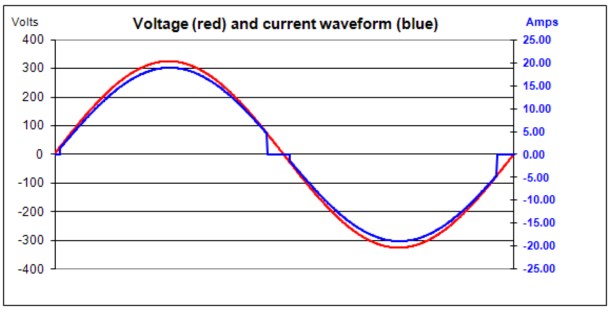
d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A to create a waveform/spectrum as shown below, with a conduction angle from 4° to 166°. The expected harmonics currents for a load of 17 Ω are specified in Table 5. If the load is not exactly 17 Ω adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3 % I_f + 5 mA), of the actually generated harmonic currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value is within ±1 %, of the actually generated powers.

h) Perform the test and compare the obtained data with the expected results, as specified in the tables. If the test reveals errors beyond the tolerances specified in this Technical Report, and the analyzer or test system have hardware or software adjustments, several of the tests may be used to make the adjustments needed to minimize the errors and thus improve the overall accuracy and the frequency response. A subsequent test is then performed to document the improved results.



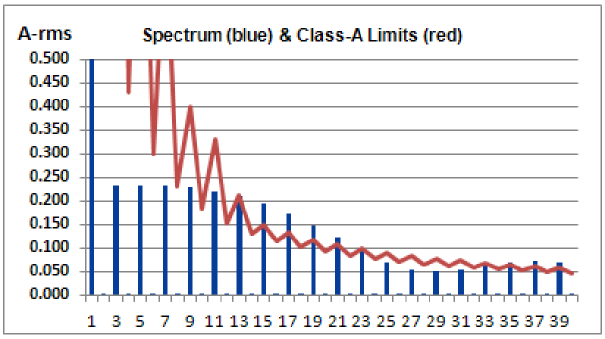


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Figure 3 – Waveform and spectrum for tests 3a and 3b

Table 5 – Spectrum and data of test 3 for 17 Ω, at 4° to 166°

Calculated parameters	
Linear load resistance / Ω	100 000
Control load resistance / Ω	17,0
System voltage / V	230,00
Peak voltage / V	325,27
Power / W	3 102,28
Apparent power / VA	3 107,03
Power factor	0,998
Current crest factor	1,416
Current THD / %	5,0
Current THC / A	0,670
Partial odd harmonic current (POHC) / A	0,237
Current / A	13,509
Peak current / A	19,134
Start phase / °	4
Stop phase / °	166

Harmonic number	**Amplitude** / A
1	13,490 1
2	0,000 0
3	0,230 9
4	0,000 0
5	0,231 5
6	0,000 0
7	0,230 8
8	0,000 0
9	0,227 6
10	0,000 0
11	0,220 6
12	0,000 0

Harmonic number	Amplitude / A
13	0,209 1
14	0,000 0
15	0,192 8
16	0,000 0
17	0,172 1
18	0,000 0
19	0,147 7
20	0,000 0
21	0,121 2
22	0,000 0
23	0,094 6
24	0,000 0
25	0,070 8
26	0,000 0
27	0,054 3
28	0,000 0
29	0,049 8
30	0,000 0
31	0,055 2
32	0,000 0
33	0,063 5
34	0,000 0
35	0,069 9
36	0,000 0
37	0,072 2
38	0,000 0
39	0,070 0
40	0,000 0

9.7 Test no. 3b – Class B at ~3 000 W with higher orders passing Class B limits

9.7.1 Rationale

This test with a load similar to test 3a is to verify that the analyzer evaluates the results correctly versus Class B limits. If the analyzer or power source specifications are limited to currents less than those required for this test, this test may be operated at the maximum obtainable power for the AC power source. The waveform is shown in Figure 3 of the previous test no 3a, and the “zoomed” spectrum is shown in Figure 4, showing the Class B limits.

9.7.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 % of expected values, and that the voltage distortion values meet of IEC 61000-3-2:2014, Clause A.2.

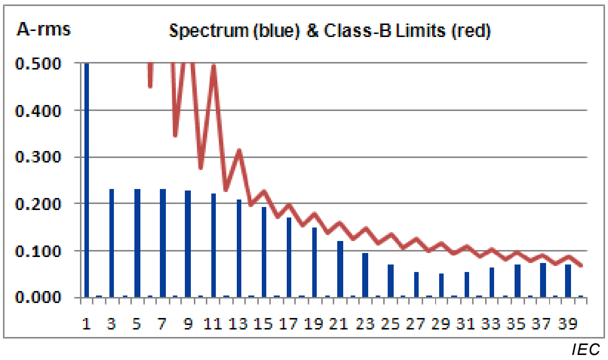
d) Either use a suitable programmable load or the harmonics generation/load unit illustrated in Annex A to create a waveform/spectrum as shown below, with a conduction angle from 4° to 166°. The expected harmonics currents for a load of 17,2 Ω are specified in Table 6. If the load is not exactly 17,2 Ω adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA) of the actually generated harmonic currents (i.e. expected or ideal values).

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value is within ±1 %, of the actually generated powers.

h) Perform the test and compare the obtained data with the expected results, as specified in the tables following the waveform and spectrum graph. If the test reveals errors beyond the tolerances specified in this Technical Report, and the analyzer or test system have hardware or software adjustments, several of the tests may be used to make the adjustments needed to minimize the errors and thus improve the overall accuracy and the frequency response. A subsequent test is then performed to document the improved results.



NOTE The waveform is identical to test 3a.

Figure 4 – Spectrum for test 3b passing Class B

Table 6 – Spectrum and data of test 3b for 17 Ω, at 4° to 166°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	17,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	3 102,28
Apparent power / VA	3 107,03
Power factor	0,998
Current crest factor	1,416
Current THD / %	5,0
THC / A	0,670
Partial odd harmonic current (POHC) / A	0,237
Current / A	13,509
Peak current / A	19,134
Start phase / °	4
Stop phase / °	166

Harmonic number	**Amplitude** / A
1	13,490 1
2	0,000 0
3	0,230 9
4	0,000 0
5	0,231 5
6	0,000 0
7	0,230 8
8	0,000 0
9	0,227 6
10	0,000 0
11	0,220 6
12	0,000 0
13	0,209 1
14	0,000 0
15	0,192 8
16	0,000 0
17	0,172 1
18	0,000 0
19	0,147 7
20	0,000 0
21	0,121 2
22	0,000 0
23	0,094 6
24	0,000 0
25	0,070 8
26	0,000 0
27	0,054 3
28	0,000 0
29	0,049 8
30	0,000 0
31	0,055 2
32	0,000 0
33	0,063 5
34	0,000 0
35	0,069 9
36	0,000 0
37	0,072 2
38	0,000 0
39	0,070 0
40	0,000 0

9.8 Test no. 4 – Class B at ~1 000 W with harmonics that fail Class B limits

9.8.1 Rationale

This test is with a 41 Ω load and a smaller conduction angle, to verify harmonics that fail Class B limits. The waveform and spectrum are shown in Figure 5.

9.8.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 % of the expected value, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A to create a waveform and spectrum as shown in Figure 5, with a conduction angle from 60° to 155°. The expected harmonics currents for a load of 41 Ω are specified in Table 7. If the load is not exactly 41 Ω adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA) of the actually generated, i.e. ideal, harmonic currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value is within ±1 %, of the actually generated powers.

h) If the system has adjustments available, either via hardware or software, the voltage, current, power, and – if applicable – PF values of this test may be used to calibrate/adjust the analyzer.

NOTE Harmonics no. 17, 21, 23, and 25 fail by a good margin, while other odd harmonics are close to or just over the limits for this Class B test.

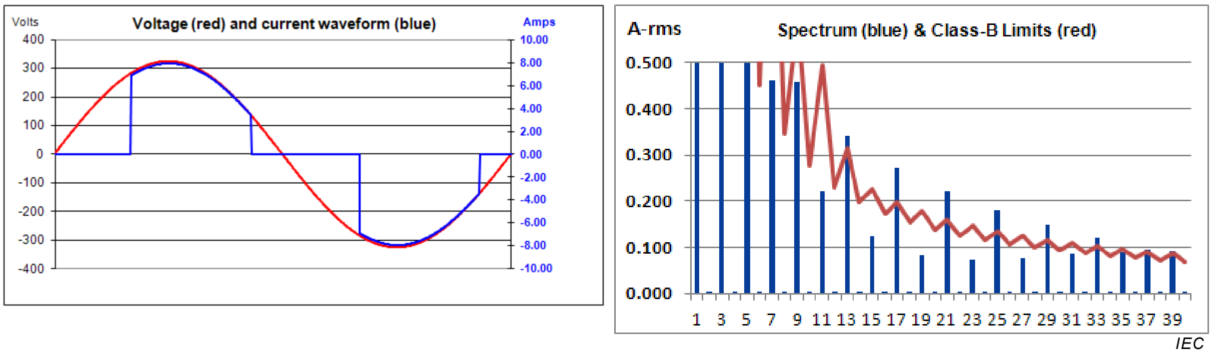


Figure 5 – Waveform and spectrum for test 4

Table 7 – Spectrum and data for test 4 for 41 Ω, at 60° to 155°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	41,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	1 016,74
Apparent power / VA	1 145,44
Power factor	0,888
Current crest factor	1,593
Current THD / %	44,5
THC / A	2,020
Partial odd harmonic current (POHC) / A	0,402
Current / A	4,980
Peak current / A	7,935
Start phase / °	60
Stop phase / °	155

Harmonic number	**Amplitude** / A
1	4,535 7
2	0,000 0
3	1,655 7
4	0,000 0
5	0,706 2
6	0,000 0
7	0,460 1
8	0,000 0
9	0,456 3
10	0,000 0
11	0,220 7
12	0,000 0
13	0,341 3
14	0,000 0
15	0,124 0
16	0,000 0
17	0,270 7
18	0,000 0
19	0,083 2
20	0,000 0
21	0,220 2
22	0,000 0
23	0,073 6
24	0,000 0
25	0,180 5

Harmonic number	Amplitude / A
26	0,000 0
27	0,077 7
28	0,000 0
29	0,147 6
30	0,000 0
31	0,084 5
32	0,000 0
33	0,119 3
34	0,000 0
35	0,090 1
36	0,000 0
37	0,094 7
38	0,000 0
39	0,093 3
40	0,000 0

9.9 Test no. 5 – Class C at ~640 W with harmonics that just pass the limits

9.9.1 Rationale

This test verifies that with an 80 Ω load and specified conduction angles, the system determines a 'pass Class C'. The waveform and spectrum are shown in Figure 6.

NOTE The Class C limits are proportional to current. Therefore, for systems with a smaller power source, or an analyzer with limited current capability, this test no. 5 can be run at a higher load resistance, such as ~160 Ω or even 320 Ω, without affecting the pass/fail result or the harmonic current percentages versus the limits. The harmonics are proportionally lower for a higher load resistance.

9.9.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 % of the expected value, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a conduction angle from 7° to 148°. The expected harmonic currents for a load of 80 Ω are specified in Table 8. If the load is not exactly 80 Ω, adjust the expected spectrum (and limits) proportionally.

e) Verify that the measured values are within ±(0,3 % I_f + 5 mA), of the actually generated harmonic current currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value and the overall current are within ±1 % of the actually generated “ideal” values, and that the PF is within 1 % ± 0,01 of the actually generated value.

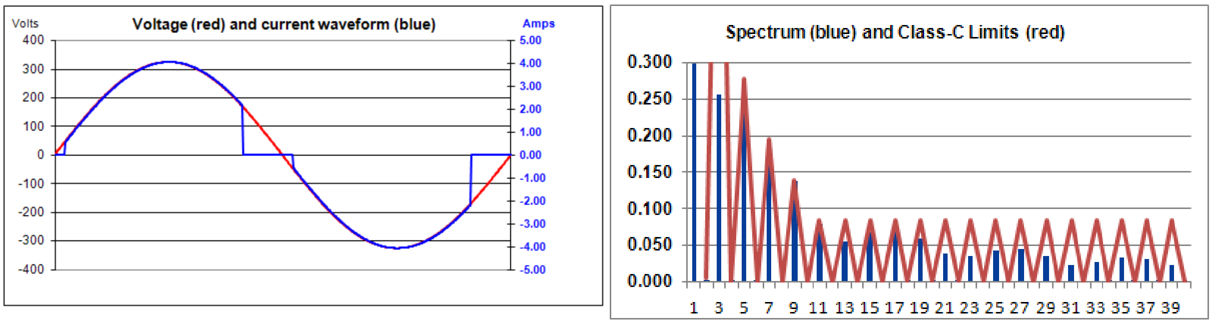


Figure 6 – Waveform and spectrum for test 5 passing Class C limits

Table 8 – Spectrum and data of test 5 for 80 Ω, at 7° to 148°

Calculated parameters	
Linear load resistance / Ω	1 000 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	638,13
Apparent power / VA	649,78
Power factor	0,982
Current crest factor	1,440
Current THD / %	16,5
THC / A	0,459
Partial odd harmonic current (POHC) / A	0,109
Current / A	2,825
Peak current / A	4,069
Start phase / °	7
Stop phase / °	148

Harmonic number	**Amplitude** / A
1	2,785 4
2	0,000 0
3	0,256 9
4	0,000 0
5	0,233 0
6	0,000 0
7	0,191 9
8	0,000 0
9	0,137 4
10	0,000 0
11	0,083 0
12	0,000 0
13	0,056 1
14	0,000 0

Harmonic number	**Amplitude** / A
15	0,065 0
16	0,000 0
17	0,071 0
18	0,000 0
19	0,060 5
20	0,000 0
21	0,041 2
22	0,000 0
23	0,033 3
24	0,000 0
25	0,041 4
26	0,000 0
27	0,044 7
28	0,000 0
29	0,037 1
30	0,000 0
31	0,025 7
32	0,000 0
33	0,025 2
34	0,000 0
35	0,031 8
36	0,000 0
37	0,032 2
38	0,000 0
39	0,025 1
40	0,000 0

9.10 Test no. 6 – Class C at ~560 W with harmonics that fail the limits

9.10.1 Rationale

This test verifies that with an 80 Ω load and specified conduction angles, the system determines a “fail Class C”. The waveform and spectrum are shown in Figure 7.

NOTE The Class C limits are proportional to current. Therefore, for systems with a smaller power source, or an analyzer with limited current capability, this test no. 6 can be run at a higher load resistance, such as 160 Ω or even 320 Ω, without affecting the pass/fail result or the harmonic current percentages versus the limits. The harmonics are proportionally lower for a higher load resistance.

9.10.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.
b) Configure the AC power source for 230 V ±0,23 V, 50 Hz.
c) Record the power, voltage, and current readings of the harmonic analyzer and verify they are within ±1 % of the expected values, such as those specified in Table 9 and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a conduction angle from 54° to 160°. The expected harmonics values for a load of 80 Ω are specified in Table 8. If the load is not exactly 80 Ω adjust the expected spectrum (and limits) proportionally.

e) Verify that the measured values are within ±(0,3% I_f +5 mA), of the actually generated harmonic currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power and current values are within ±1 % of the actually generated values, and that the PF is within 1 % ±0,01 of the actually generated value.

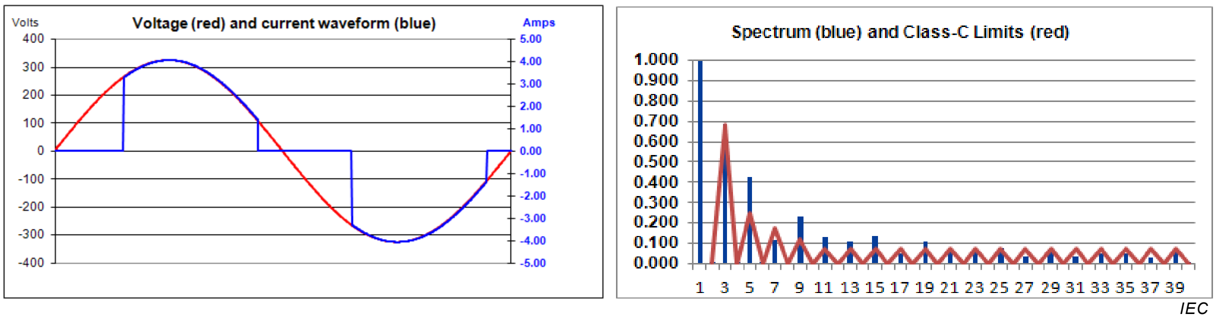


Figure 7 – Waveform and spectrum for test 6 failing Class C limits

Table 9 – Spectrum and data of test 6 for 80 Ω, at 54° to 160°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	557,86
Apparent power / VA	607,51
Power factor	0,918
Current crest factor	1,540
Current THD / %	36,6
THC / A	0,905
Partial odd-order current (POHC) / A	0,177
Current / A	2,641
Peak current / A	4,069
Start phase / °	54
Stop phase / °	160

Harm no.	**Amplitude** / A
1	2,475 0
2	0,000 0
3	0,689 9
4	0,000 0
5	0,427 4
6	0,000 0

Harm no.	Amplitude / A
7	0,120 0
8	0,000 0
9	0,231 4
10	0,000 0
11	0,128 4
12	0,000 0
13	0,112 5
14	0,000 0
15	0,134 3
16	0,000 0
17	0,050 7
18	0,000 0
19	0,108 8
20	0,000 0
21	0,061 6
22	0,000 0
23	0,068 6
24	0,000 0
25	0,076 9
26	0,000 0
27	0,034 3
28	0,000 0
29	0,072 4
30	0,000 0
31	0,036 5
32	0,000 0
33	0,052 4
34	0,000 0
35	0,051 4
36	0,000 0
37	0,028 5
38	0,000 0
39	0,054 1
40	0,000 0

9.11 Test no. 7 – Class D at ~540 W with harmonics that pass the limits

9.11.1 Rationale

This test is with an 80 Ω load and conduction angles, causing harmonics that pass Class D. The spectrum is as shown in Figure 8.

9.11.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 % of the expected values, such as specified in Table 10, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown in Figure 8, with a conduction angle from 45° to 135°. The expected harmonics currents for a load of 80 Ω are specified in Table 8. If the load is not exactly 80 Ω adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA) of the actually generated harmonic current values.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value is within ±1 %, of the actually generated powers, and that the PF is within 1 % ±0,01 of the actually generated value.

NOTE The Class D limits are proportional to power. This test presents a load at the higher end of Class D Therefore, for systems with a smaller power source, or an analyzer with limited current capability, this test no. 7 can be run with a higher load resistance, such as 160 Ω, or 320 Ω (136 W). Loads below 75 W are outside of the Class D power range. Of course, the harmonics are proportionally lower for a higher load resistance.

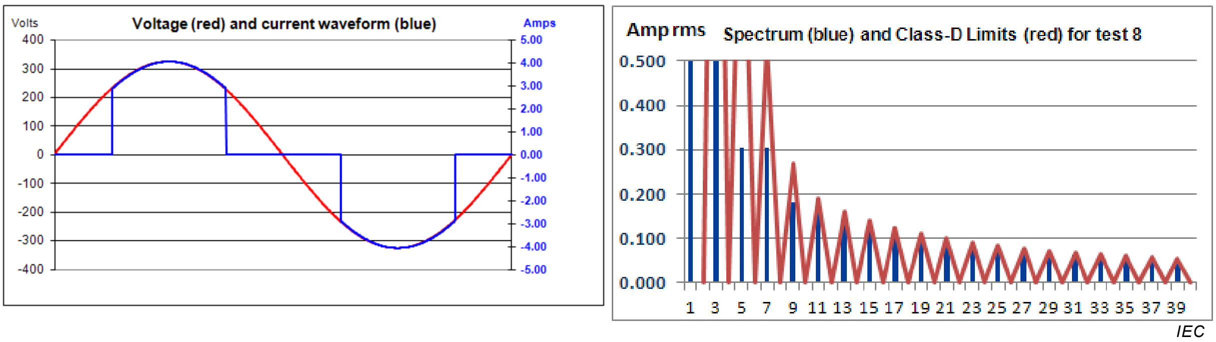


Figure 8 – Spectrum of test 7 just passing Class D

Table 10 – Spectrum and data of test 7 for 80 Ω, at 45° to 135°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	541,55
Apparent power / VA	598,55
Power factor	0,905
Current crest factor	1,563
Current THD / %	46,3
THC / A	1,089
Partial odd order current (POHC) / A	0,204
Current / A	2,602
Peak current / A	4,069
Start phase / °	45
Stop phase / °	135

Harmonic number	**Amplitude** / A
1	2,354 6
2	0,000 0
3	0,915 0
4	0,000 0
5	0,305 0
6	0,000 0
7	0,305 0
8	0,000 0
9	0,183 0
10	0,000 0
11	0,183 0
12	0,000 0
13	0,130 8
14	0,000 0
15	0,130 7
16	0,000 0
17	0,101 7
18	0,000 0
19	0,101 7
20	0,000 0
21	0,083 3
22	0,000 0
23	0,083 2
24	0,000 0
25	0,070 5
26	0,000 0
27	0,070 4
28	0,000 0
29	0,061 1
30	0,000 0
31	0,061 1
32	0,000 0
33	0,053 9
34	0,000 0
35	0,053 9
36	0,000 0
37	0,048 3
38	0,000 0
39	0,048 3
40	0,000 0

9.12 Test no. 8 – Class D at ~380 W with harmonics that fail the limits

9.12.1 Rationale

This test verifies that with an 80 Ω load and specified conduction angles the system fails the Class D test. The waveform and spectrum are as shown in Figure 9.

9.12.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ± 1 %, such as specified in Table 11 and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a conduction angle from 45° to 106°. The expected harmonics currents for a load of 80 Ω are specified in Table 8. If the load is not exactly 80 Ω adjust the expected spectrum (and limits) proportionally.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA) of the actually generated harmonic currents.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

g) Verify that the measured power value is within ±1 %, of the actually generated powers, and that the PF is within 1 % ±0,01 of the actually generated value.

NOTE This test could be run at a higher or lower load resistance, with proportionally lower or higher harmonics, and limit. A load above 600 W or below 75 W is outside of the Class D range.

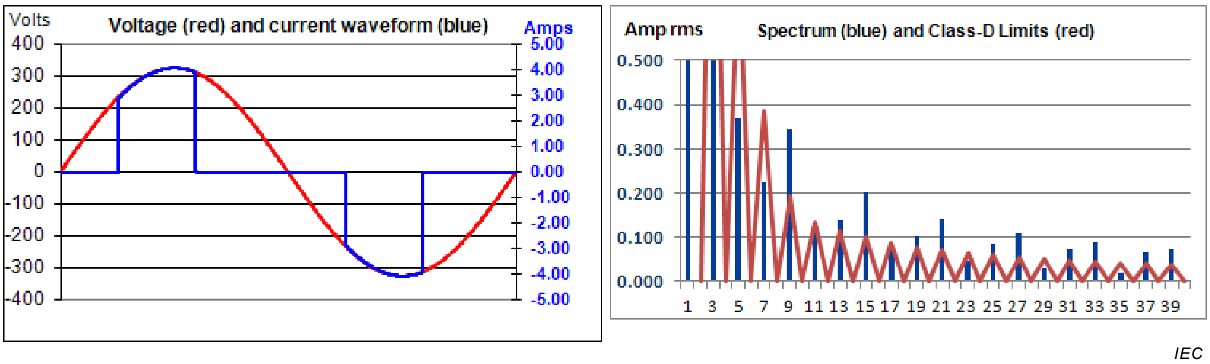


Figure 9 – Waveform and spectrum for test 8 failing Class D

Table 11 – Spectrum and data of test 8 for 80 Ω, at 45° to 106°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	386,19
Apparent power / VA	505,36
Power factor	0,764
Current crest factor	1,852
Current THD / %	77,8
THC / A	1,341
Partial odd harmonic current (POHC) / A	0,256
Current / A	2,197
Peak current / A	4,069
Start phase / °	45
Stop phase / °	106

Harmonic number	**Amplitude** / A
1	1,724 0
2	0,000 0
3	1,154 6
4	0,000 0
5	0,370 3
6	0,000 0
7	0,223 3
8	0,000 0
9	0,344 0
10	0,000 0
11	0,132 3
12	0,000 0
13	0,138 0
14	0,000 0
15	0,203 3
16	0,000 0
17	0,072 7
18	0,000 0
19	0,103 6
20	0,000 0
21	0,143 3
22	0,000 0
23	0,045 7
24	0,000 0
25	0,084 8

Harmonic number	Amplitude / A
26	0,000 0
27	0,109 8
28	0,000 0
29	0,030 4
30	0,000 0
31	0,072 9
32	0,000 0
33	0,088 1
34	0,000 0
35	0,020 7
36	0,000 0
37	0,064 5
38	0,000 0
39	0,072 9
40	0,000 0

9.13 Test no. 9 – Class D at ~540 W with harmonics that pass the POHC limit

9.13.1 Rationale

This test with an 80 Ω load and specified conduction angles results in several high order harmonics exceeding the 100 % Class D limits, but the test passes because of the POHC allowance. The waveform and spectrum are shown in Figure 10. The test should result in a "PASS" condition.

9.13.2 Test procedure

The following list details the test procedure:

a) Follow the common procedure steps in 9.2.

b) Configure the AC power source for 230 V ±0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 %, such as specified in Table 12, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A to create a waveform/spectrum as shown in Figure 10, with a conduction angle from 20° to 122°. The expected harmonic currents for a load of 80 Ω are specified in Table 8. If the load is not exactly 80 Ω, adjust the expected spectrum proportionally.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA), of the actually generated harmonic currents, such as specified in Table-12.

f) Verify that the system produces a "PASS" result for this test.

g) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

h) Verify that the measured power value is within ±1 %, of the actually generated powers, and that the PF is within 1 % ± 0,01 of the actually generated value.

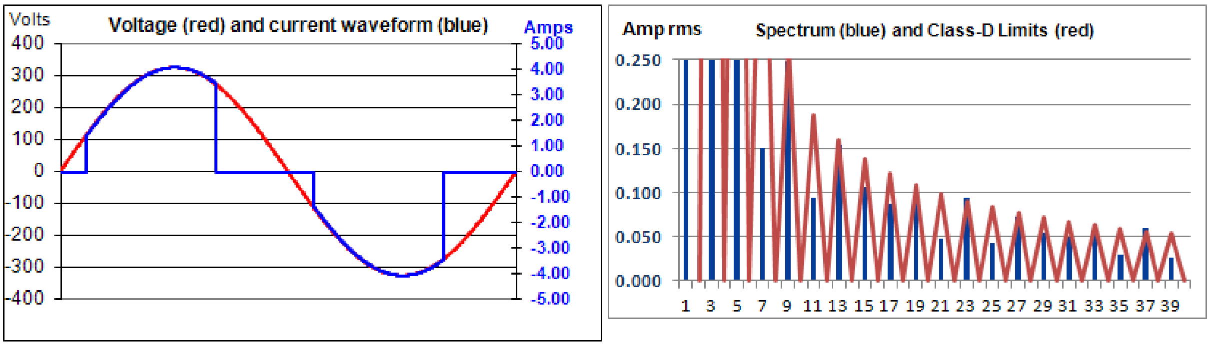


Figure 10 – Waveform and spectrum for test 9 passing POHC

Table 12 – Spectrum and data of test 9 for 80 Ω, at 20° to 122°

Calculated parameters	
Linear load resistance / Ω	100 000
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	538,40
Apparent power / VA	596,81
Power factor	0,902
Current crest factor	1,568
Current THD / %	39,8
THC / A	0,957
Partial odd harmonic current (POHC) / A	0,180
Current / A	2,595
Peak current / A	4,069
Start phase / °	20
Stop phase / °	122

Harmonic number	**Amplitude** / A
1	2,404 6
2	0,000 0
3	0,752 9
4	0,000 0
5	0,411 1
6	0,000 0
7	0,151 2
8	0,000 0
9	0,247 9
10	0,000 0
11	0,094 4
12	0,000 0
13	0,153 5
14	0,000 0

Harmonic number	Amplitude / A
15	0,106 4
16	0,000 0
17	0,087 6
18	0,000 0
19	0,107 5
20	0,000 0
21	0,047 2
22	0,000 0
23	0,094 8
24	0,000 0
25	0,042 3
26	0,000 0
27	0,073 3
28	0,000 0
29	0,054 2
30	0,000 0
31	0,048 9
32	0,000 0
33	0,061 1
34	0,000 0
35	0,029 2
36	0,000 0
37	0,058 9
38	0,000 0
39	0,026 2
40	0,000 0

9.14 Test no. 10 – Class A test at ~680 W with higher order harmonics failing the POHC limit

9.14.1 Rationale

This test is to verify that the instrument properly determines a Class A failure at 650 W, for higher order harmonics only, due to the POHC limit being exceeded, and measures the current and voltages with the required accuracy at this power.

9.14.2 Test procedure

The following list details the test procedure:

a) Follow the steps outlined in 9.2.
b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.
c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ± 1 %, and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.
d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a controlled load conduction angle from 55° to 59°. The expected harmonics currents for these loads are as

specified in Table 13, and as illustrated in Figure 11. If necessary adjust the spectrum proportionally to controlled load changes.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA) of the actually generated harmonic currents, and that POHC is 0,274 ± 2,5 %.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

NOTE 1 POHC equals 0,274 A and fails the POHC limit for Class A of 0,251 A.

NOTE 2 A deviation in the controlled load of 1 % can cause a POHC deviation of 1,1 % while causing ≤ 0,1 % change in power, current or I–THD. Also deviations of 0,2° in phase angle settings for the 59° point can affect the POHC by more than 2,5 %.

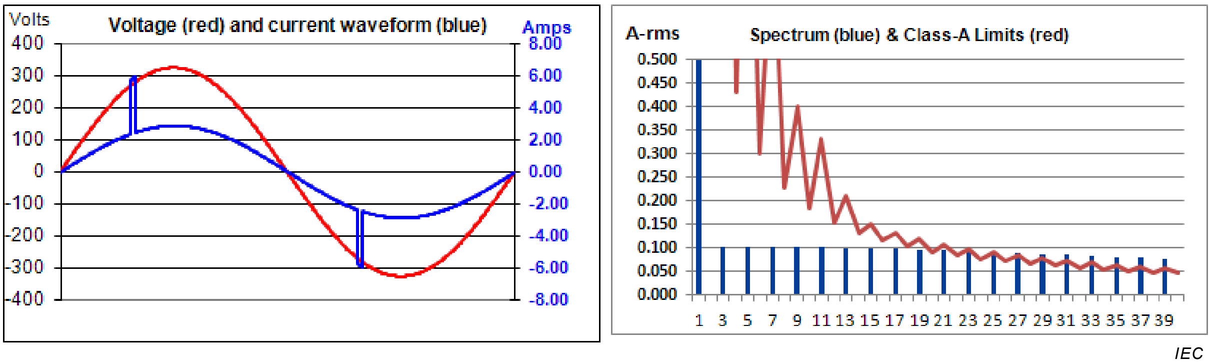


Figure 11 – Waveform and spectrum for test 10 failing POHC for Class A

Table 13 – Spectrum and data of test 10 for 80 Ω linear and 80 Ω controlled load, at 55° to 59°

Calculated parameters	
Linear load resistance / Ω	80,0
Controlled load resistance / Ω	80,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	681,19
Apparent power / VA	690,52
Power factor	0,986
Current crest factor	2,314
Current THD / %	13,8
THC / A	0,408
Partial odd harmonic current (POHC) / A	0,274
Current / A	3,002
Peak current / A	6,949
Start phase / °	55
Stop phase / °	59

Harmonic number	**Amplitude** / A
1	2,962 3
2	0,000 0
3	0,103 3

Harmonic number	**Amplitude** / A
4	0,000 0
5	0,103 0
6	0,000 0
7	0,102 6
8	0,000 0
9	0,101 9
10	0,000 0
11	0,101 2
12	0,000 0
13	0,100 3
14	0,000 0
15	0,099 2
16	0,000 0
17	0,098 0
18	0,000 0
19	0,096 6
20	0,000 0
21	0,095 1
22	0,000 0
23	0,093 5
24	0,000 0
25	0,091 8
26	0,000 0
27	0,089 9
28	0,000 0
29	0,087 9
30	0,000 0
31	0,085 8
32	0,000 0
33	0,083 6
34	0,000 0
35	0,081 2
36	0,000 0
37	0,078 8
38	0,000 0
39	0,076 3
40	0,000 0

9.15 Test no. 11 – Class A at ~740 W to test analyzer and source dynamic range

9.15.1 Rationale

This test produces about 11 A (peak), at just 3,5 A (r.m.s.). It is intended to test the analyzer dynamic range and the power source peak current capability. The test pattern is illustrated in Figure 12. Of course, the POHC is very high for this test, at almost 3 times the limit.

9.15.2 The following list details the test procedure

The following list details the test procedure:

a) Follow the steps outlined in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 % and that the voltage distortion values meet IEC 61000-3-2:2014, Clause A.2.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a controlled load conduction angle from 66° to 72°. The expected harmonic currents for these loads are specified in Table 14. If necessary adjust the spectrum proportionally to controlled load changes. The waveform is similar to that shown in Figure 13, with the current consisting of a linear load, with a narrow peak super-imposed on the linear waveform, for a peak current of ~11,4 A. As illustrated in Figure 12, it is likely that the source voltage waveform is slightly distorted, due to the sharp peak current. Provided the harmonic currents are within their specified tolerances, the small disturbance on the voltage waveform is acceptable.

e) Verify that the measured values are within ±(0,3 % I_f + 5 mA), of the actually generated harmonic currents. If the stop phase angle has an error of + 0,2° the lower order harmonics may deviate up to 20 mA with respect to the ideal values. Therefore care is required to minimize phase errors for this test, in order to reduce errors to less than (0,3 % + 5 mA). Alternatively, the test may be run with a linear load of ~40 Ω instead of ~80 Ω in which case the (0,3 % + 5 mA) at an r.m.s current of 6 A provides a permitted tolerance of 23 mA.

f) Repeat steps c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

The screenshot in Figure 14 illustrates a test similar to test no. 12, which is an aggravated version of test no. 11. Depending on linear and controlled load settings, the peak current can be set to at least 17,5 A and up to as much as 30 A. It tests the power analyzer for dynamic range, and verifies that the instrument detects the narrow peak, and ranges accordingly. If the power source is unable to handle this test, or if the power analyzer has insufficient dynamic range, the testing authority may still issue a certificate that the system is suitable for most testing according to IEC 61000-3-2 and IEC 61000-4-7.

NOTE Even though the test load for this test no. 12 is not an absolute worst case, it represents a sufficiently demanding analysis task for compliance test systems.

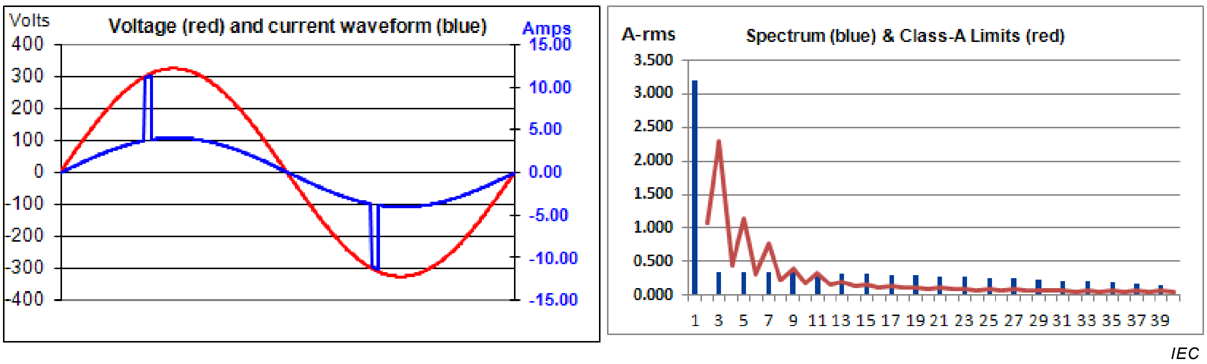


Figure 12 – Waveform and spectrum for test 11

Table 14 – Spectrum data of test 11 for 80 Ω linear and 41 Ω controlled load, at 66° to 72°

Calculated parameters	
Linear load resistance / Ω	80,0
Controlled load resistance / Ω	41,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	735,75
Apparent power / VA	794,93
Power factor	0,926
Current crest factor	3,296
Current THD / %	37,7
THC / A	1,207
Partial odd harmonic current (POHC) / A	0,709
Current / A	3,456
Peak current / A	11,393
Start phase / °	66
Stop phase / °	72

Harmonic number	**Amplitude** / A
1	3,201 4
2	0,000 0
3	0,345 9
4	0,000 0
5	0,343 4
6	0,000 0
7	0,339 7
8	0,000 0
9	0,334 8
10	0,000 1
11	0,328 7
12	0,000 1
13	0,321 4
14	0,000 1
15	0,313 1
16	0,000 1
17	0,303 8
18	0,000 1
19	0,293 4
20	0,000 1
21	0,282 2
22	0,000 1
23	0,270 1
24	0,000 1

Harmonic number	Amplitude / A
25	0,257 3
26	0,000 1
27	0,243 7
28	0,000 1
29	0,229 6
30	0,000 1
31	0,215 0
32	0,000 1
33	0,200 0
34	0,000 1
35	0,184 6
36	0,000 1
37	0,169 0
38	0,000 1
39	0,153 2
40	0,000 1

9.16 Test no. 12 – Class A at 1 400 W with > 30 A peak current

9.16.1 Rationale

This test produces a peak >17 A, at an r.m.s. current of just 6,4 A. It is intended to test the analyzer dynamic range and the power source peak current capability. The test pattern is illustrated in Figures 13 and 14. Of course, the POHC value is even higher for this test, and is over 3 times the limit value.

9.16.2 Test procedure

The following list details the test procedure:

a) Follow the steps outlined in 9.2.

b) Configure the AC power source for 230 V ± 0,23 V, 50 Hz.

c) Record the power, voltage, and current reading of the harmonic analyzer and verify it is within ±1 %.

d) Either use a suitable programmable load, or the harmonics generation/load unit illustrated in Annex A, to create a waveform/spectrum as shown below, with a controlled load conduction angle from 66° to 72°. The expected harmonic currents for these loads are specified in Table 15. If necessary adjust the spectrum proportionally to controlled load changes. The waveform is similar to that shown in Figure 12, with the current consisting of a linear load, with a narrow peak super-imposed on the linear waveform, for a peak current of ~17 A. As illustrated in Figure 14, it is likely that the source voltage waveform is slightly distorted, due to the sharp peak current. This might increase the peak current slightly. Provided the harmonic currents are within their specified tolerances, the small disturbance on the voltage waveform is acceptable.

e) Verify that the measured values are within ±(0,3% I_f + 5 mA), of the actually generated harmonic currents.

f) Repeat step c), d) and e) for a mains frequency of 60 Hz if the system is also specified for use at 60 Hz.

NOTE This aggravated test is optional, and is mainly intended to test the power source peak current capability and the dynamic range of the analyzer.

The tested system normally monitors the voltage distortion during harmonics tests, to make sure that the voltage distortion meets the requirements of IEC 61000-3-2:2014, Clause A.2. If any of the voltage harmonics exceed the requirements of IEC 61000-3-2:2014, Clause A.2, the actual observed values should be included in the calibration/verification report.

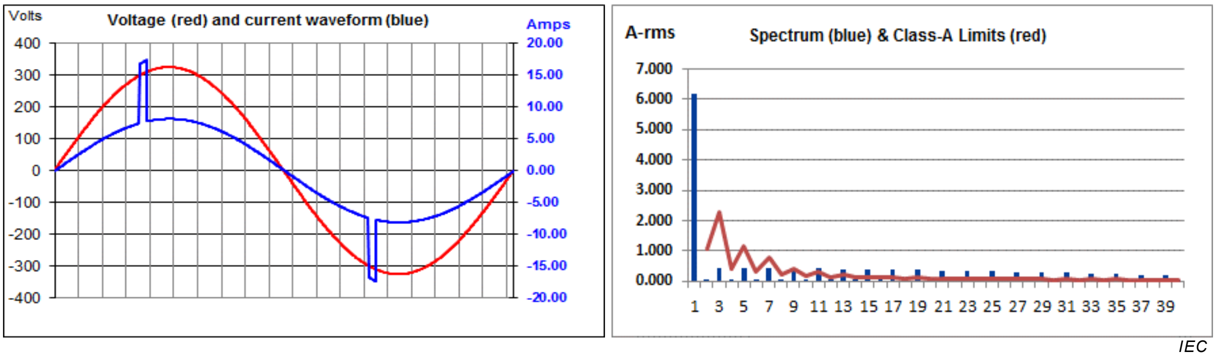
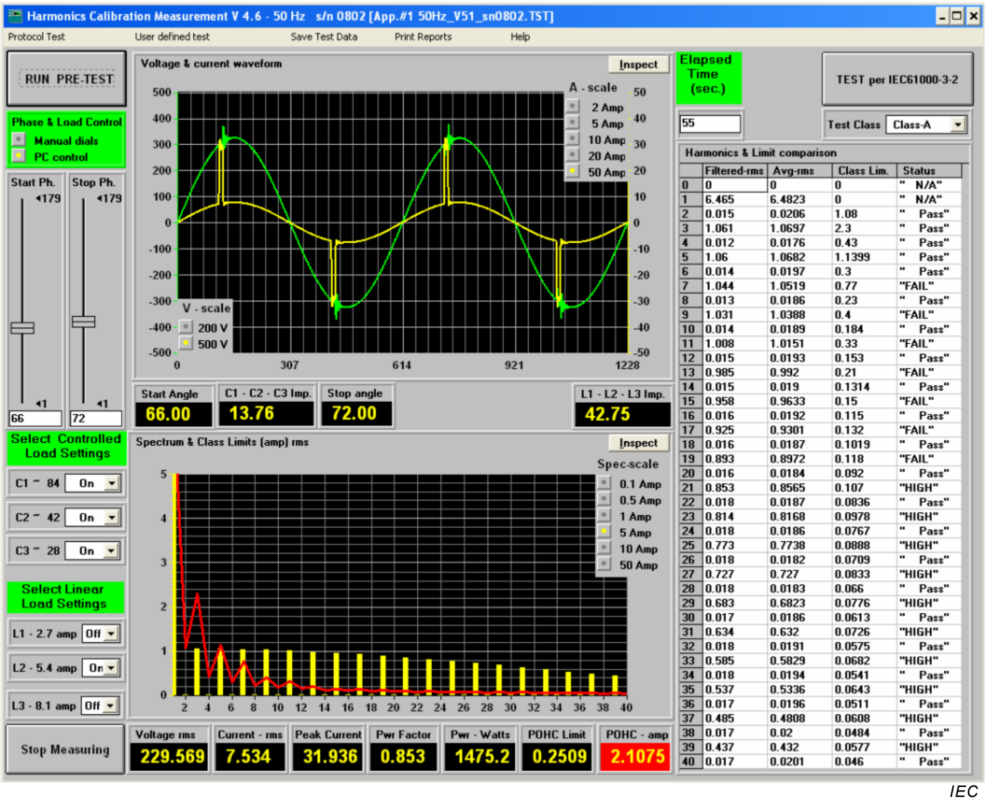


Figure 13 – Calculated ideal waveform and spectrum for test 12



The slight distortion that is visible in the measurement screen is common for the type of demanding load represented by test no. 12. The slight aberration has a frequency with a period of only a small fraction of a millisecond, and thus does not affect the harmonic analysis up to 2 kHz.

Figure 14 – Waveform and spectrum for test 12, showing slightly distorted source voltage

Table 15 – Spectrum data of test 12 for 41 Ω linear and 32 Ω controlled load, at 66° to 72°

Calculated parameters	
Linear load resistance / Ω	41,0
Controlled load resistance / Ω	14,0
System voltage / V	230
Peak voltage / V	325,27
Power / W	1508,44
Apparent power / VA	1747,06
Power factor	0,863
Current crest factor	3,896
Current THD / %	53,8
THC / A	3,534
Partial odd order harmonic current (POHC) /A	2,077
Current / A	7,596
Peak current / A	29,591
Start phase / °	66
Stop phase / °	72

Harmonic number	**Amplitude** / A
1	6,568 6
2	0,000 0
3	1,013 1
4	0,000 1
5	1,005 8
6	0,000 1
7	0,994 9
8	0,000 1
9	0,980 5
10	0,000 1
11	0,962 6
12	0,000 2
13	0,941 4
14	0,000 2
15	0,917 0
16	0,000 2
17	0,889 6
18	0,000 2
19	0,859 3
20	0,000 3
21	0,826 4
22	0,000 3
23	0,791 0
24	0,000 3

Harmonic number	**Amplitude** / A
25	0,753 4
26	0,000 3
27	0,713 8
28	0,000 3
29	0,672 5
30	0,000 3
31	0,629 6
32	0,000 3
33	0,585 6
34	0,000 3
35	0,540 6
36	0,000 3
37	0,494 9
38	0,000 3
39	0,448 7
40	0,000 3

10 Spreadsheet support program to compute harmonics and user guide

A spreadsheet that can be used with several popular office programs is available to the user of this Technical Report, to compute the expected – or ideal – harmonic values for the type of harmonics generation unit detailed in Annex A. This support program, as an essential supplement to this Technical Report, is provided in accordance with IEC Administrative Circular AC/40/2009.

A user guide for the spreadsheet is also provided to guide the user in entering the appropriate values, and obtaining the correct calculation results.

The IEC and the spreadsheet author disclaim liability for any personal injury, property or any other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from this software and the document upon which its methods are based, use of, or reliance upon.

Annex A
(informative)

Test setup and requirements for external equipment

A.1 Example test setup for calibration and verification waveforms

A typical compliance test system setup is shown in Figure A.1. Most compliance test systems are suitable for both harmonics and flicker testing, hence the IEC TR 60725 reference impedance is also shown in the diagram, but is, of course, in bypass mode for harmonics tests.

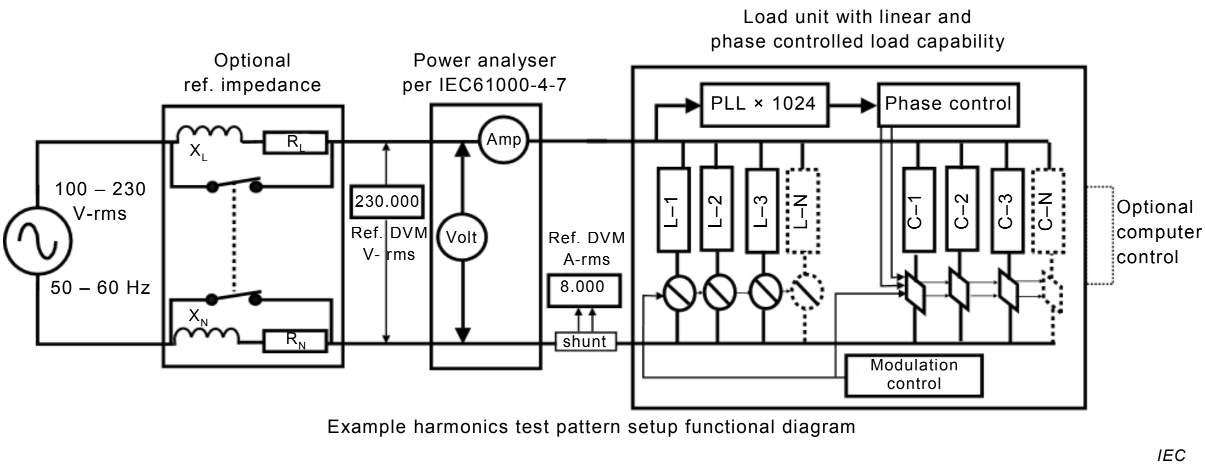


Figure A.1 – Typical test setup for tests no. 1 to 12

The load unit can be implemented with a series of linear loads, and a set of phase controlled loads. The phase controlled loads can be turned On/Off at user defined phase angles, as shown in the figures for each test.

DVM-1 measures the current in conjunction with the shunt, while DVM-2 measures the applied voltage. Both measure the same values as seen by the harmonics analyzer of the compliance test system, and thus allow the verification (and possibly adjustment) of the overall voltage and current measurement accuracy of the analyzer.

The loads used in the above example need to be resistive, with minimal parasitic inductance or capacitance. At 2 000 Hz (2 400 Hz) the load inductance should be such that the total load impedance is within 0,5 % of the resistive load value at 50/60 Hz, thus at 500 Hz or 1 000 Hz the deviations should be minimal.

A suitable method to verify the load characteristics is to apply a sinusoidal voltage of sufficient amplitude and measure the current flow. By varying the voltage, the current through the resistive load can be measured at multiple power values. Most power sources for compliance test systems also have the capability to generate a higher frequency, such as 500 Hz, and thus the load response at 500 Hz can be compared to the response at 50 Hz or 60 Hz. Since most good quality bench DVMs are specified to at least 1 000 Hz, the DVM-1 and DVM-2 shown in the above example can be used for the verification of the resistive load.

Also, the shunt requires very low parasitic inductance and capacitance, which explains the specification of ±0,1 % from 50 Hz to 2 400 Hz for the shunt in Clause A.5.

A.2 Sine wave test

The calibration method described in this Technical Report is also capable of producing just linear waveforms, suitable for overall voltage and current calibration purposes. Some harmonics analysis measurement systems are calibrated with a sine wave, and derive their accuracy from an accurate calibration of their digitizing circuits. An example of such a simple sinusoidal waveform, set to 1,000 A, is shown in Figure A.2. The user may also check the power-analyzer voltage input range by setting the compliance test system power source to an over-voltage of 10 % above the nominal test voltage(s).

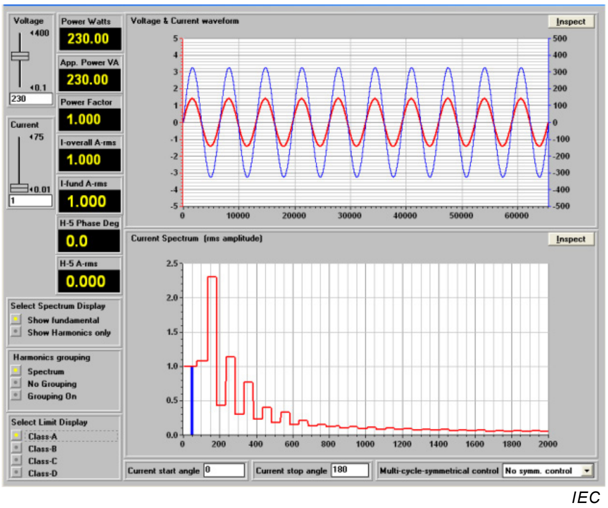


Figure A.2 – Sinusoidal calibration waveform at 1,000 A

The measurement result, of course, includes both the distortion of the power source and any non-linearity of the power analysis instrument. The results of such test can be helpful to understand the limitation of the measurement system, and the result of this over-voltage may be tabulated in the test report, including the voltage distortion for all voltage harmonics up to at least H_{40}.

Various sinusoidal currents can be produced using the calibration load shown schematically in Figure A.1. It is also possible to modulate the load pattern, and this type of modulation can be added in a future version of this Technical Report.

A.3 Load modulation to generate interharmonics

Modulation patterns as shown in Figure A.3, including the addition of a DC offset via a half wave rectified circuit, can be used to verify that the harmonics analyzer has no-gap data acquisition. These functions, including multi-cycle-symmetrical control (MCSC) simulation can be added to this Technical Report at a later time.

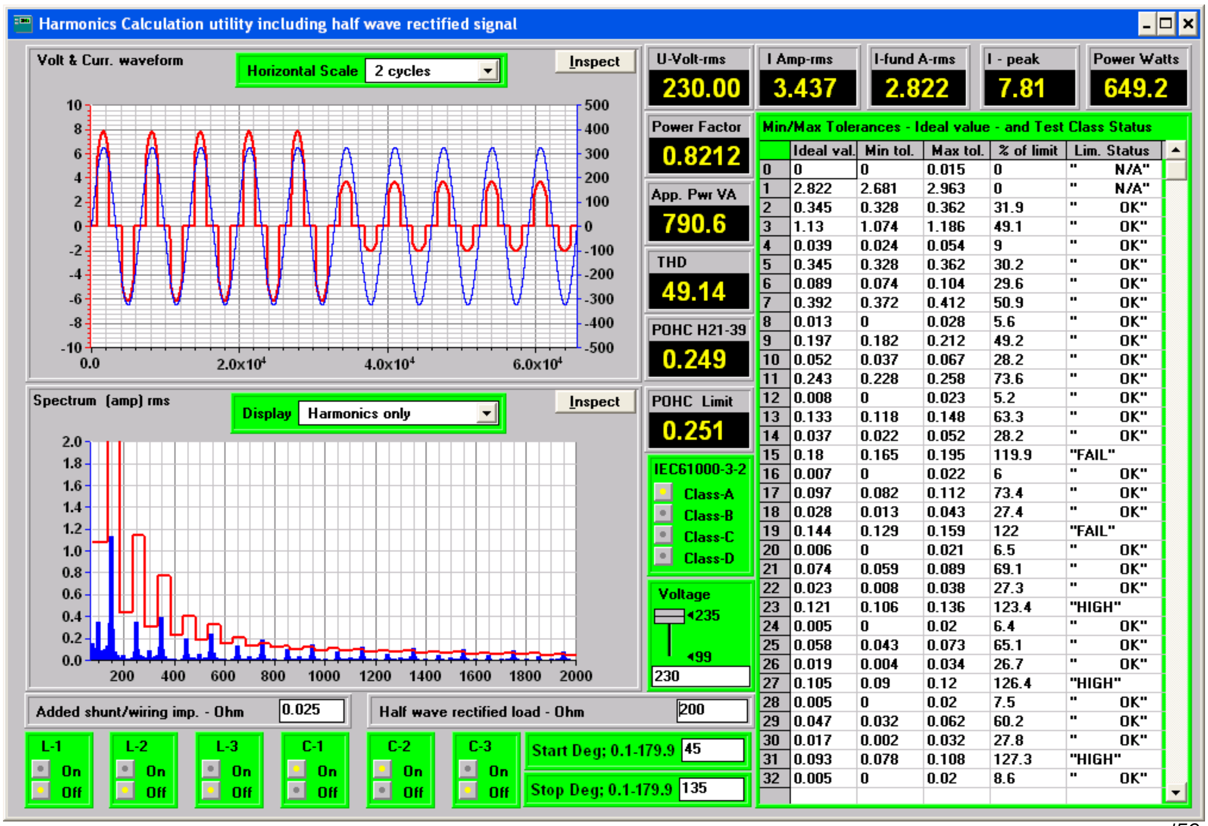


Figure A.3 – A modulated load showing side-bands that can be used to test inter-harmonics

A.4 Using a square wave to test analysis functions

A relatively simple test to verify the analysis function and bandwidth of a power analyzer, is to apply a square wave signal to the voltage input, with the analyzer forced to the measurement scale required to record the voltage to be measured. Provided the rise time is fast enough, and the waveform is symmetrical, i.e. has a 50 % duty cycle, the Fourier analysis should yield a defined response with the odd harmonics having an amplitude equal to $1/n \times I_f$ or U_f and all angles equal to zero where n is the odd harmonic order and I_f or U_f is the fundamental current or voltage.

For example, a square wave with an r.m.s. voltage of 1,11 V has a fundamental of 1,000 V, a 3rd harmonic component of 0,333 V, a 5th harmonic of 0,200 V, and a 7th harmonic of 0,143 V (i.e. $1/n$ times the fundamental amplitude). If a voltage input is tested, and a square wave from a power amplifier is applied, the user needs to verify that the voltage rise time and fall time of the square wave is faster than 0,05 ms (50 µs) and that the duty cycle is 50 % ±0,3 %. If the rise/fall time is slower, or the duty cycle deviates, the spectrum deviates as well. For example, the amplitude of the higher order harmonics – such as the 37th and 39th harmonics – are attenuated too much if the rise/fall time is too slow. Figure A.4 illustrates a square wave with an amplitude of 1,11 V and the associated harmonic spectrum. Note that the spectrum is proportional to the square wave voltage, i.e. the user can select the amplitude according to the tested range of the power analysis instrument. In general, the bigger the amplitude, the better it is. To test the voltage range of an instrument that is used for 120 V (60 Hz) systems, a 9 V amplitude suffices.

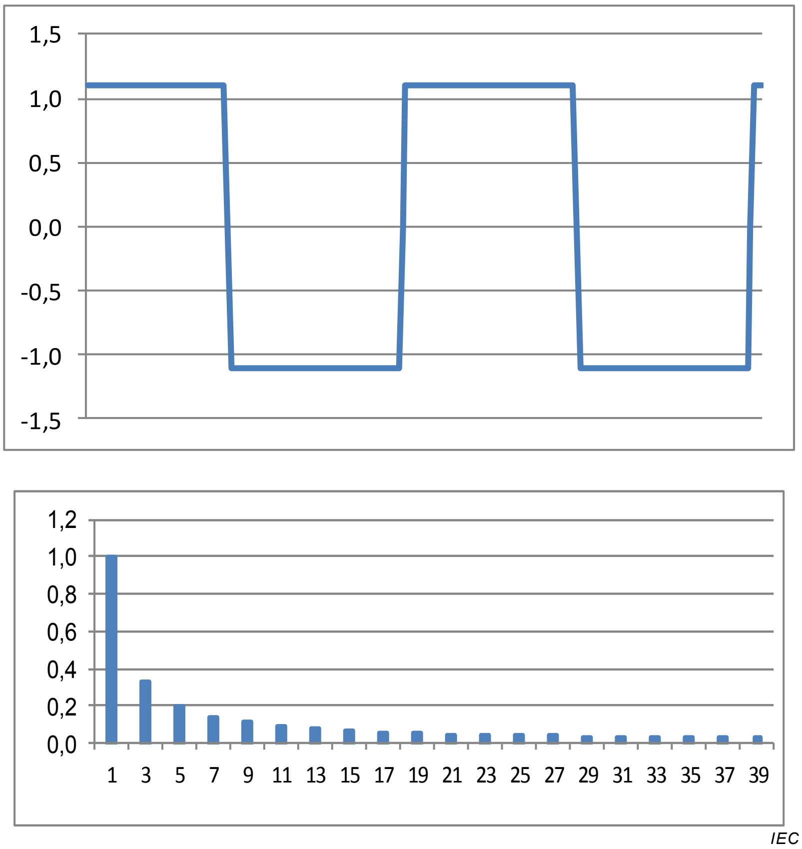


Figure A.4 – 1,11 V square wave and the associated spectrum up to H_{39}

Ideally, a square wave with a larger amplitude should be used for the 230 V range, but most function generators, capable of generating high accuracy square waves, are limited to an output voltage of 10 V maximum into a high impedance, which is sometimes also specified as 10 V into an open circuit, or 5 V maximum into a 50 Ω load. Most power analyzers will operate in either a 400 V or 500 V (peak) range for a 230 V r.m.s (325 V peak) input voltage. Even though 9 V does not really test the linearity of an instrument that operates in a peak 500 V range, it is still a good test of the Fourier analysis system. For instruments that have the capability to record and store the spectra for every 200 ms, a 30-min stability test could also be performed. For this test, the amplitude is kept constant and the recorded data is subsequently analyzed for maximum, average, and minimum values, and the results are tabulated in the test report.

Figure A.5 shows the ideal spectrum data for a 9 V square wave, along with the so-called compatibility values, calculated for a 120 V system. The green triangles in Figure A.5 indicate the maximum distortion that a power source is permitted to have (in percent of the r.m.s. value).

A square wave only has odd harmonic components, so the spectrum illustration and Table A.1 only show these odd harmonics.

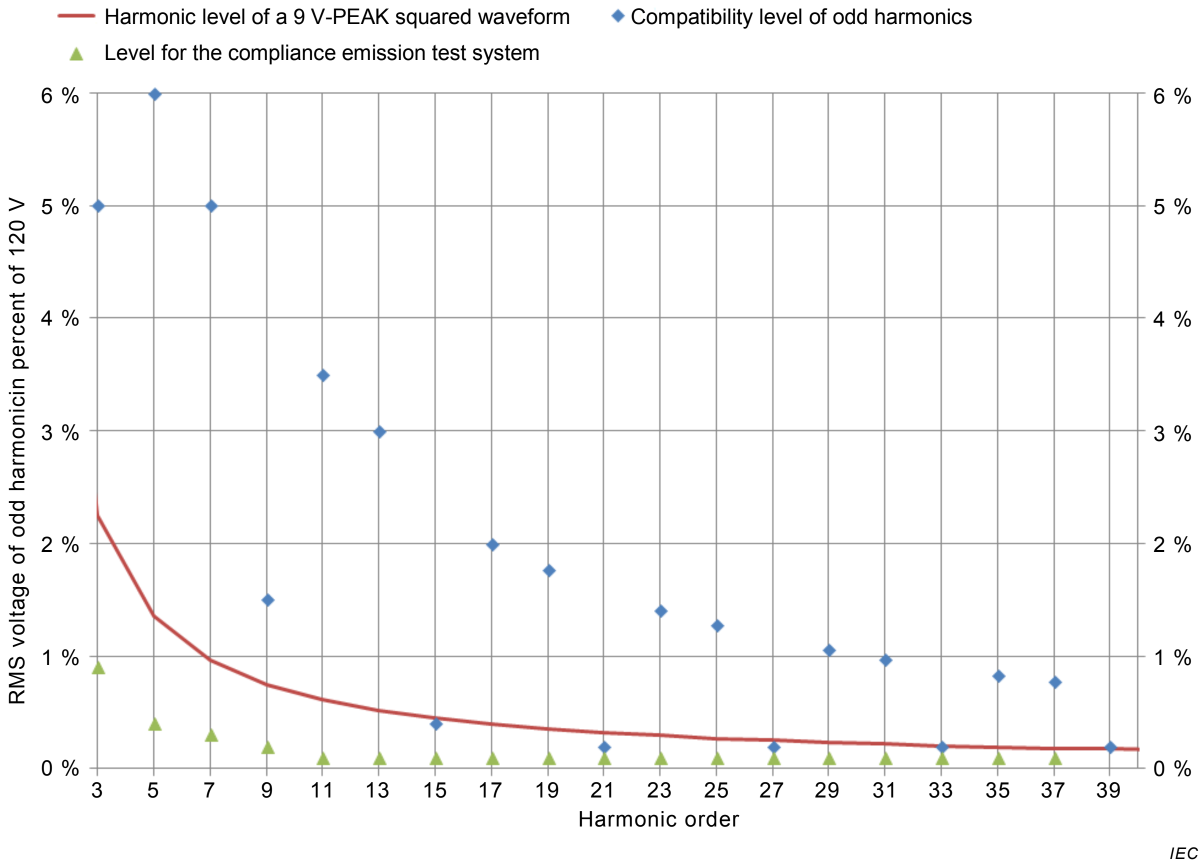


Figure A.5 – Spectrum data for a 9 V square wave compared against compatibility values

Table A.1 – Ideal spectrum data and minimum and maximum measured values during stability test

Order	Ideal	Measured		Order	Ideal	Measured		Order	Ideal	Measured	
		Min.	Max.			Min.	Max.			Min.	Max.
1	8,103	8,024	8,168	15	0,540	0,535	0,545	29	0,279	0,277	0,282
3	2,701	2,675	2,723	17	0,477	0,472	0,480	31	0,261	0,259	0,263
5	1,621	1,605	1,634	19	0,427	0,422	0,430	33	0,246	0,243	0,248
7	1,158	1,146	1,167	21	0,386	0,382	0,389	35	0,232	0,229	0,233
9	0,900	0,892	0,908	23	0,352	0,349	0,355	37	0,219	0,217	0,221
11	0,737	0,729	0,743	25	0,324	0,321	0,327	39	0,208	0,206	0,209
13	0,623	0,617	0,628	27	0,300	0,297	0,303				

A.5 Requirements for external test equipment to verify accuracy

The following list provides detailed requirements for external test equipment, used to verify accuracy per this protocol:

- Digital voltmeter (DVM) accuracy for frequency range 50 Hz to 2 400 Hz
- RMS voltage for 100 V to 250 V ± 0,1 % of reading
- RMS voltage for 0,1 V to 1 V ± 0,1 % of reading ±0,1mV
- Direct r.m.s. current measurement < 1 A ± 0,1 % of reading ±0,3 mA

- Direct r.m.s. current measurement < 10 A ± 0,1 % of reading ±1 mA
- Current shunt accuracy ±0,1 % from 50 Hz to 2 400 Hz
- Recommended shunt values
  - ≤ 100 mΩ for current ≤ 2,5 A
  - 10 mΩ for current ≤ 16 A
  - 1 mΩ or 10 mΩ for current from 16 A to 75 A
- Timing characteristics of the waveform need to be verified with an uncertainty of ±2 μs.

Annex B
(informative)

Error analysis of the methods specified in this Technical Report

Table B.1 shows the result of load impedance or phase errors. The comparison is limited to the odd harmonics, as the even harmonics of the test patterns are negligible, which they generally are also in the 'real world EUTs. If a product has significant amounts of even harmonics, it generally indicates non-symmetrical current flow, which in turn constitutes asymmetrical control. This is prohibited according to IEC 61000-3-2:2014, 6.1, unless certain (exceptional) conditions are present. Table B.1 below shows the result of a ±1 % impedance error, which results in minor deviations, as mentioned earlier in this Technical Report.

Table B.1 – Errors in harmonic current values due to incorrect applied voltage or load impedance, or phase errors

Harmonic order	Ideal value	Minimum acceptable value	Maximum acceptable value	+1 % impedance error	Resulting current error mA	-1 % impedance error	Resulting current error mA	+0,2° phase error	Sign of error for +0,2°	-0,2° phase error	Sign of error for -0,2°
3	1,044	1,036	1,052	1,033	-11,0	1,054	10,0	1,041	-	1,046	+
5	0,653	0,646	0,660	0,646	-7,0	0,659	6,0	0,655	+	0,651	-
7	0,231	0,225	0,237	0,229	-2,0	0,234	3,0	0,237	+	0,226	-
9	0,097	0,092	0,102	0,096	-1,0	0,098	1,0	0,091	-	0,103	+
11	0,257	0,251	0,263	0,255	-2,0	0,260	3,0	0,254	-	0,260	+
13	0,243	0,237	0,249	0,241	-2,0	0,245	2,0	0,245	+	0,241	-
15	0,113	0,108	0,118	0,112	-1,0	0,114	1,0	0,119	+	0,108	-
17	0,042	0,037	0,047	0,042	0,0	0,043	1,0	0,036	-	0,048	+
19	0,143	0,138	0,148	0,142	-1,0	0,145	2,0	0,140	-	0,146	+
21	0,152	0,147	0,157	0,150	-2,0	0,153	1,0	0,153	+	0,150	-
23	0,081	0,076	0,086	0,080	-1,0	0,082	1,0	0,086	+	0,075	-
25	0,021	0,016	0,026	0,021	0,0	0,021	0,0	0,015	-	0,027	+
27	0,096	0,091	0,101	0,095	-1,0	0,097	1,0	0,092	-	0,100	+
29	0,111	0,106	0,116	0,111	0,0	0,112	1,0	0,112	+	0,110	-
31	0,065	0,060	0,070	0,065	0,0	0,066	1,0	0,070	+	0,060	-
33	0,009	0,004	0,014	0,009	0,0	0,009	0,0	0,003	-	0,015	+
35	0,070	0,065	0,075	0,070	0,0	0,071	1,0	0,066	-	0,074	+
37	0,087	0,082	0,092	0,086	-1,0	0,088	1,0	0,088	+	0,081	-
39	0,056	0,051	0,061	0,055	-1,0	0,057	1,0	0,060	+	0,051	-

As the table shows, only the 3rd harmonic is slightly outside of the reduced tolerance of ±(0,3 % + 5 mA) for a 1 % error. Note, however, that it is still well within the ±20 mA that is permitted according to IEC 61000-3-2, so the minimum and maximum acceptable values reflect the ± (0,3 % + 5 mA) verification tolerance mentioned earlier in this report. The actual permitted tolerances according to IEC 61000-3-2 therefore are substantially more relaxed.

Another possible error source – using the calibration load described in Annex A – would be if the phase control of the current flow has serious inaccuracies. As Table B.1 illustrates, phase errors of ±0,2° would also cause some harmonics to go just outside (by 1 mA or 2 mA) the stringent accuracy requirement of ±(0,3 % + 5 mA) but all values are still well within ±(1 % + 10 mA) as specified in IEC 61000-3-2. Note also, that an error in current conduction angles results in successive harmonic pairs having alternating positive and negative errors (indicated by the '+' and '-' signs), as compared to the theoretically ideal harmonic values. Entering incorrect impedance errors, on the other hand, will result in all harmonics being either too high or too low, as shown in columns 6 and 8. In the event the power source for the compliance test system has a non-linear output impedance, insufficient bandwidth, or harmonic distortion, harmonics generally have a more arbitrary pattern of deviations.

Given the foregoing, it is clear that the methods used in this Technical Report do not require exceptional accuracies in setting the load values or the current conduction angles, to achieve accuracies that are easily within the uncertainties permitted in IEC 61000-3-2.

Bibliography

[1] JIS C 61000-3-2:2011, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current <=20 A per phase)*

[2] IEC TR 60725, *Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current ≤75 A per phase*

[3] IEC Administrative Circular AC/40/2009, Guidelines for IEC Publications with a software supplement

[4] Spreadsheet Cal Technical Report 61000-4-37 support. Complement to IEC TR 61000-4-37

[5] User guide for IEC TR 61000-4-37 support spreadsheet. Complement to IEC TR 61000-4-37

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch