POWER QUALITY INSTRUMENT TESTING MADE EASY

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Abstract

The growing impact of Power Quality is illustrated by the increasing number of power quality instruments installed in the electrical network at all voltage levels. Initially this paper briefly describes the existing framework of IEC standards for testing such devices. For manufacturer type testing and comparable acceptance testing in utilities a set of test plans for guided testing of PQ meters according to IEC 62586-2 is presented. Already existing test plans provided by a test set manufacturer have been completely reworked to reflect recent changes in the standards, provide test guidance to users and specially to give substantial support for the test assessment. Findings from testing a typical PQ meter are discussed. In addition, the paper introduces a suitable subset of tests for field testing during commissioning or routine testing of PQ meters.

Keywords

Power quality, power quality instrument, type testing, test templates, IEC 61000-4-30, IEC 62586, EN 50160

1 Introduction

Due to an increasing number of distributed energy resources (like PV installations) and more and more non-conventional loads the impact of power quality (PQ) in the electrical network is constantly growing. Utilities need to proof conformity with regulating standards like EN 50160; industrial plants make contractual agreements on the quality of the energy delivered and even consumers experience effects of insufficient PQ more and more frequently. According to the European Power Quality Survey Report the costs of deficient power quality amounts to more than 150 billion € per year in the EU [1]. This trend will continue with the constantly growing use of power electronics and non-linear elements in the power grid, which are both effecting the PQ.

This leads to an increasing number of installed power quality meters in the electrical network and at connection points. Malfunctioning or reduced accuracy can have monetary impact on the operator. On the other hand, there is little experience and lacking awareness for PQ especially in small utilities, industry and at end-use customers. This is also reflected by the fact, that in the EU the investments in the improvement of PQ and in monitoring the supplied PQ make only around 10 % of the above-mentioned costs [2].

Basic requirements for a PQ monitoring system are a high measurement accuracy and full functioning of the instruments in operation. But in many cases, there is not much emphasis put on this point when installing new PQIs (power quality instruments) and in addition later checks or routine tests usually are not performed. Because other than for protection relays there are no commonly established rules or procedures for installation, routine testing or calibration. Therefore, malfunctioning or reduced accuracy can remain unnoticed although they may have significant monetary impact.

Today most PQ meters used in the HV or MV network are classified according to IEC 61000-4-30 class A or S. For these devices the standards IEC 62586-1 and -2 define requirements and type tests to be performed by the manufacturer. In principle suitable subsets of these tests could be used to qualify PQIs (acceptance testing), for installation and maintenance testing. But the tests defined in these standards are time consuming and not easy to understand. A second challenge comes with the test assessment, e.g. when postprocessing of multiple characteristic values recorded by the equipment under test is required.

But at the same time suitable test equipment may already be available: the accuracy of many state of the art protection test sets also meet the requirements for testing of PQIs. And with a test plan and the right software modules PQI testing is no longer “rocket science” but something comparable to a protection relay test.

In that regard this paper contributes to an easy, clear and practicable way of PQI testing.

2 PQ phenomena according to IEC 61000-4-30

Simply put, power quality describes the degree of conformity between an ideal sinusoidal signal and the actually present waveform of the supply in the power grid. Traditionally PQ is understood as voltage quality. But amongst the parameters of frequency and voltage it nowadays includes additional criteria like service reliability and current characteristics.

For the testing of PQIs the standard IEC 61000-4-30 lists the following parameters:

- Frequency stability
- Voltage phenomena
    - Variations of magnitude
    - Dips, swells and interruptions
    - Harmonics, interharmonics
    - Unbalance
    - Flicker
    - Rapid voltage changes
- Current phenomena
    - Variations of magnitude
    - Harmonics, interharmonics
    - Unbalance
- Mains signaling voltages

Moreover, there are tests for special device functions:

- Flagging of measurement values due to occurrence of voltage events
- Accuracy of the internal clock
- Variations of external influence quantities.

The effects from insufficient power quality reach from disturbances over outages all the way to destruction of devices connected to the power grid. Particularly dips and short interruptions as well as surges and transients emerging in the industrial environment are the main cause for financial damage [1].

3 Testing of PQIs

3.1 Standards for testing of PQIs

The normative fundamental conditions for testing of PQIs are defined in a framework of different IEC standards. This seems to be somehow confusing and therefore is briefly described in the following and visualized in Figure 1. The basis for standardization of PQ measurements is IEC 61000-4-30, where the principle methods are defined and device classifications (class A or S) including accuracy requirements are specified. This norm refers to standard IEC 62586-1 for general device specifications and to 62586-2 for the actual description of (type) testing signals. In some exceptional cases the additional standards IEC 61000-4-2, 61000-4-7 and 61000-4-15 have to be included in the testing procedure.

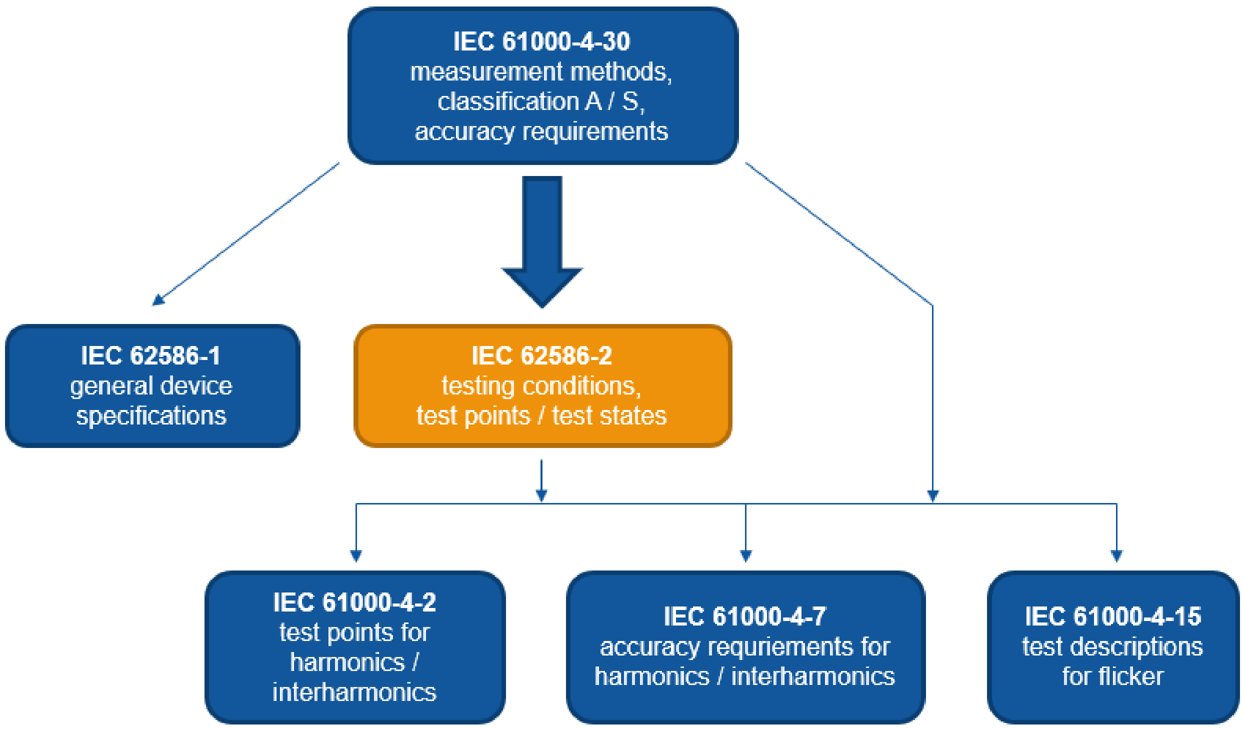

Figure 1: Framework of IEC standards for PQI testing

3.2 Test setup

Typical requirements for a test set for testing of PQIs are:

- 3 voltage output channels
- 3 current output channels
- High accuracy (corresponds to the class of the PQI instrument to be tested)
- Software modules that facilitate the correct simulation of PQ phenomena
- The test set is capable to work with automated test plans
- Tests can be started time synchronized and triggered by a time signal.

For some tests time synchronization of the test set and the PQI is mandatory. For example, this is the case where short-term flicker P_{st} or clock uncertainty must be evaluated. For many other tests time synchronization is not mandatory but very helpful for a smooth test procedure and easier assessment.

In the practical work for this paper we used the test sets OMICRON CMC 256plus and CMC430 for testing as they both meet the accuracy requirements for testing a class A PQI. The devices tested were a Siemens SICAM Q200 and an Eberle PQI-DA (both are class A instruments according to IEC 61000-4-30). For time synchronization a CMGPS 588 was connected. In many tests the CMC430 was added for reference measurements with its built-in Enerlyzer Live functionality. The complete test setup can be seen in Figure 2.

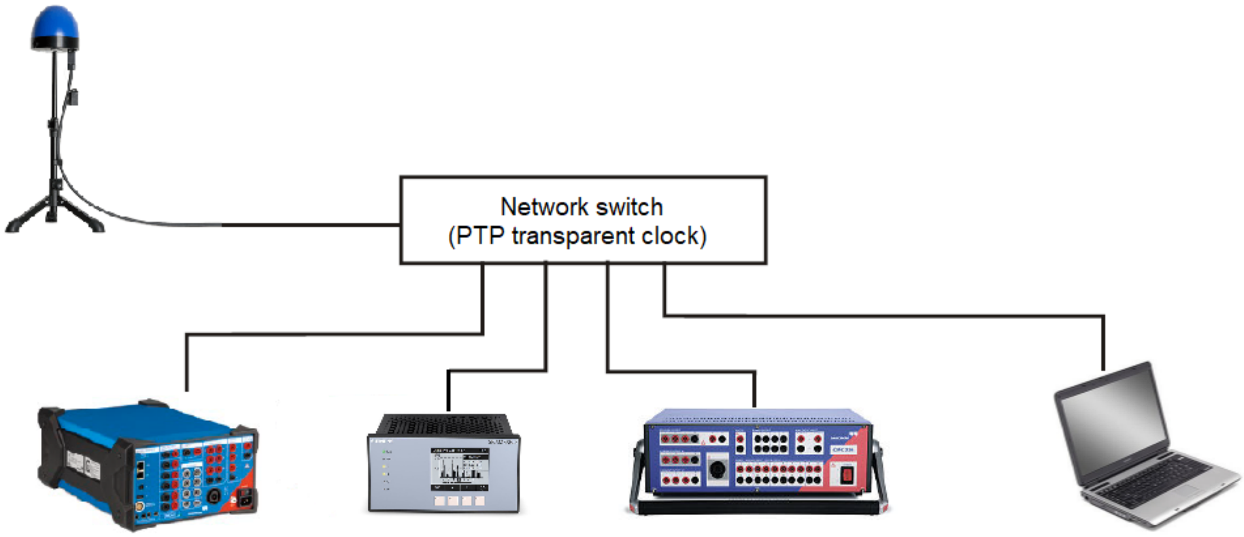

Figure 2: Test setup used for PQI testing: CMGPS (top), CMC 430 (left), SICAM Q200 (middle), CMC 256plus (right), Computer (own figure, source of individual pictures OMICRON [3] and Siemens [4]).

3.3 Test templates

Performing and assessing the tests for PQIs can be quite complicated. Therefore, test plans have been elaborated that explain the test performed and provide guidance for the user to the assessment. They contain all necessary information to run a test, like settings for the test set as well as for the test object and of course the test signal.

The test plans can automatically be adapted to the defined nominal voltage and the nominal frequency of the PQI to be tested.

With these templates the user can just start testing. He can easily perform and assess every test even without deeper specific knowledge of the standards framework presented in chapter 3.1. The templates will automatically run through all necessary tests, only interrupted by program dialogs that provide information for the user. Each template allows the user to make specific entries for the employed test set as well as for the test object. Also, the implemented tests can be adapted to any special use case; individual adaptations are possible (e.g. test steps to perform, duration of pre-incident times or phenomena related data like the flicker amplitude).

3.4 Assessment

In contrary to protection testing where the test result is dependent on a binary signal, the assessment of PQ testing takes more effort. In some cases, the user can obtain the assessment-relevant measurement values just by meter-reading from the display of the PQI. But for most test cases, the assessment is done based on the read-out of measured and calculated values from the memory of the PQ meter. Moreover, there are tests, where a post-processing of the relevant data is required for the assessment.

The created test templates will automatically ask the user for an assessment after every test. One can evaluate a test with *Passed / Failed / Not assessed*. It is always possible to change the assessment afterwards by choosing *Manual Assessment*. Therefore, our recommendation is, that one should evaluate the tests with *Not assessed* in the first step. Later, in a second step and with the use of extra tools, like Excel, the final assessment can be done.

The test templates provide user guidance for the assessment including an Excel spreadsheet for the postprocessing of test data. So, that users can do the assessment quickly without time consuming consultation of the standards.

4 Type and acceptance testing in accordance with IEC 62586

Some test plans developed for an earlier revision of IEC 62586 have already been available. In a first step these were updated and extended to cover all tests defined by IEC 62586-2. Only a few tests were omitted e.g. for temperature influence. The templates are complemented by a user manual to additionally support the user in PQI testing.

The mentioned program dialogs, that supply the user with essential information to each single test, shall make it superfluous to read through any IEC standard. At the same time, the structure of every template is in accordance with the related chapter in IEC standard 62586-2. The same is valid for the test numeration and nomination. So, if anyone needs additional information, it can be found quickly.

This allows users to perform a type or acceptance test. Of course, these tests are mainly done by manufacturers of PQIs or bigger utilities in case of a prequalification for certain PQI devices. But the ease of use, the simple test setup and the option to use test sets already available for protection testing widens the range of possible users. In chapter 5 it is discussed how a suitable subset of these tests can be used for onsite testing during commissioning and maintenance.

4.1 Test case examples

Most of the required testing conditions can be implemented based on simple characteristic signal forms as ramps, sequences or the variation of one or two voltage or current parameters. But it is also possible to represent seemingly complicated signals as in the following equation from IEC 62586-2 [5]:

$$u_H(t) = \sqrt{2}U_{din} \cdot \cos(2\pi f_n t + \varphi_n) + [1 + A_m \cdot \cos(2\pi f_m t + \varphi_m)] \cdot 0{,}1 \cdot \sqrt{2}U_{din} \cdot \cos(2\pi M f_n t + \varphi_M) \tag{1}$$

with:	$u_H(t)$	Voltage over time, index H for harmonic content	V
	U_{din}	Nominal voltage	V
	f_n, f_m	Nominal frequency, modulating frequency	Hz
	φ_n, φ_m, φ_M	Phase of fundamental, modulating, harmonic signal	°
	A_m	Modulating amplitude	V
	M	Harmonic order	-

The “translation” of the formula would be: output of a harmonic voltage signal at a certain harmonic order that is modulated at f_m and added to the nominal voltage.

For many test signals we performed reference measurements to verify that accuracy and timing of the output signal meet the requirements given in the standard. Figure 3 shows an example of a test case as described in the standard and Figure 4 the output from the test set of the same signal.

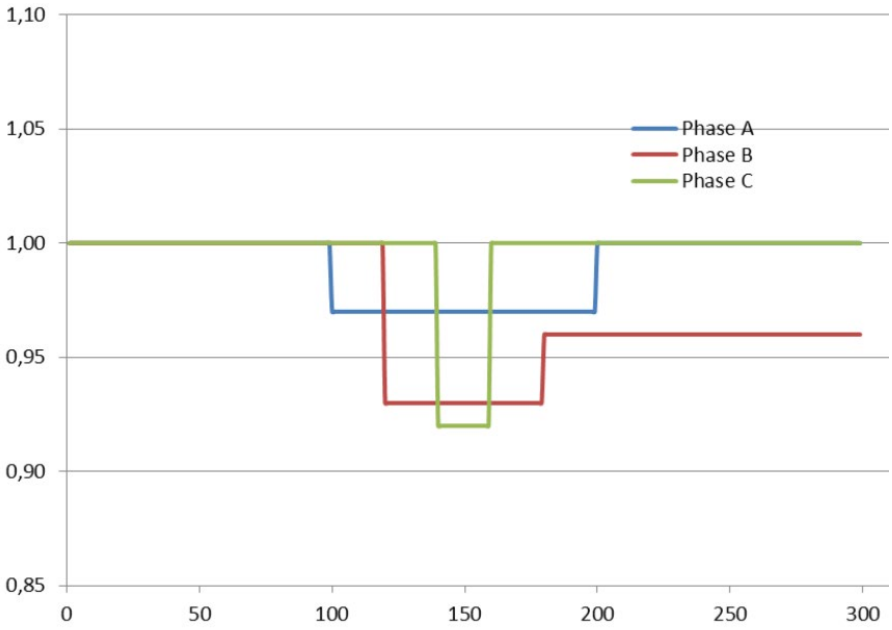

Figure 3: Test signal as described in the standard; x-axis time in half-cycles; y-axis: voltage in *pu* (source: IEC 62586-2 [5])

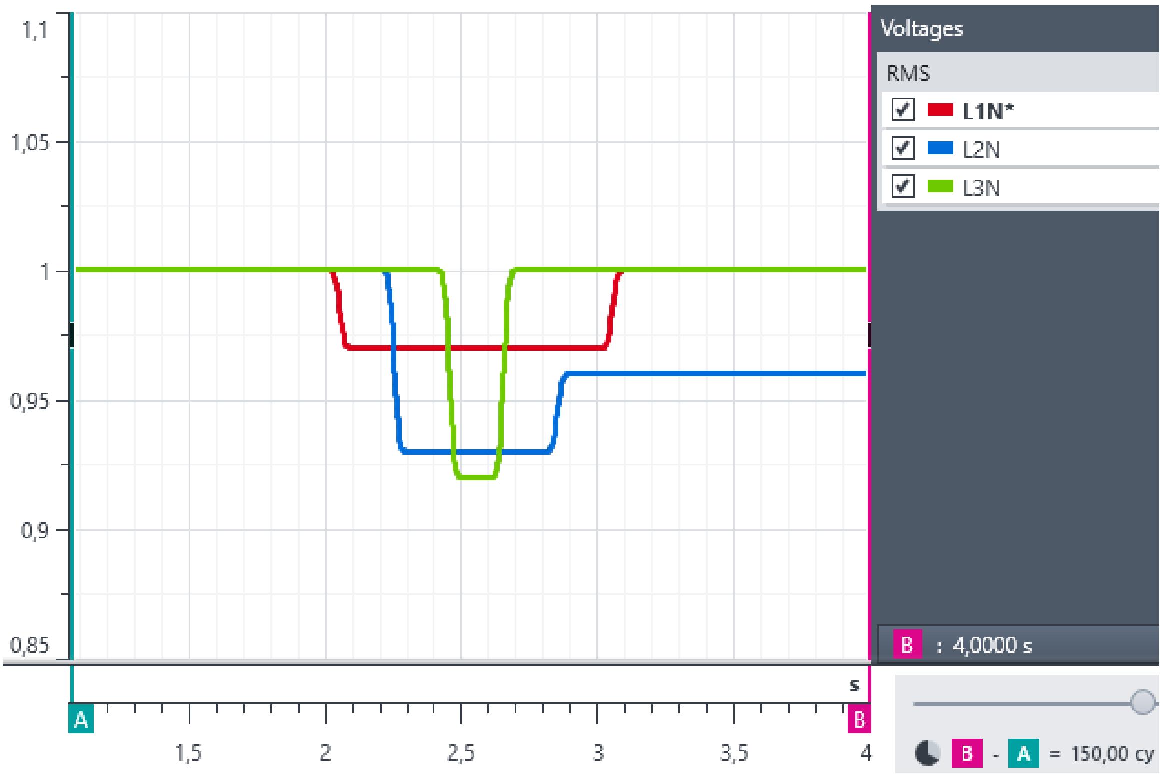

Figure 4: Test signal from reference measurement

4.2 Findings from testing PQIs using the templates

As general findings, we firstly found out that the templates are implemented properly and executable and that they produce the test signals as required. Secondly, we realized, that it takes about two weeks to run and asses all tests defined in IEC 62586-2 (even with the time savings realized by the templates).

More particular findings concern time synchronization and the correct adjustment of *pre- and post-incident times*. Time synchronization and the time-triggered start of tests will make the assessment of measurement values much easier and for some tests it is even mandatory to use an external time source. For example, these are all tests, where the *gapless and non-overlapping measurement* is checked, because a certain sequence of measurement values has to be assessed. As well as it is needed for all kind of *aggregation of measurement values* tests, which must start to the next full ten minutes. The signal before an incident (*pre-incident time*) and after an incident (*post-incident time*) is characterized by an output of nominal values and represents the normal state of the power grid. For the majority of the tests, where instantaneous values are assessed, these times are less important, because of the PQ analyzers' high measurement rate and accuracy. But coexistent there are tests, as for short-term flicker P_{st}, where a defined *pre-incident time* is needed. This is because of the P_{st} is established over ten minutes and an abrupt step from zero output to the specified test signal will lead to an incorrect measurement value. A similar problem in this context is, that the required accuracy for the maximum instantaneous flicker $P_{inst,max}$ is first reached after some minutes of constant incident output. Moreover, these settling time differs from one PQI to another, following our examination.

4.3 Limitations and improvement opportunities

We realized different limitations of the used hardware for the test setup as well as from the software.

- The main issue regarding the used software *Test Universe* is, that the specific test module for PQ phenomena offers restricted settings and test options for certain test signals, as for harmonics and interharmonics on currents. These tests have been added in the last revision of the standard and apparently the PQ module has not been extended accordingly yet.

- The auxiliary DC voltage output of the CMC 256plus is limited to 264 VDC. Depending of the device to be tested a higher output voltage may be required in one test (an additional standard DC voltage source may be needed).

- The standard defines preferred nominal voltages and currents for PQIs (including PQI devices with direct connection). Again, depending on the PQI device the output range for voltage amplitudes may not be sufficient for directly connected PQ meters. However, for the most common types of PQIs and all PQI devices connected via instrument transformers there is no problem.

- The internal system clock of the CMC256plus for the output of analog quantities is 10 kHz. So, analog output samples are generated every 0.1 ms. For the tests on phase jumps, each occurring on every phase exactly at the zero crossing, this has to be considered. At 50 Hz this would mean a time delay between the phases of 6,67 ms ($t = \frac{1}{3} \cdot 20\,ms = 6,\overline{66}\,ms$). In this case deliberated rounding must be done when defining the test (template). Figure 5 shows the output signals:
  a) without appropriate rounding. The phase jumps do not occur exactly at the zero crossing.
  b) with appropriate rounding. In this case the remaining delay is by far within the accuracy boundaries for testing PQIs of class A.

Figure 5: Output signals of phase jumps test; a) without appropriate rounding (upper); b) with appropriate rounding (lower)

5 Routine testing

For installation or routine testing the number of test cases must be significantly decreased. The test duration must be reduced from 2 weeks to e.g. 2 h (similar to the times for protection relay testing).

At first, we excluded tests that are not useful for installation or routine tests based on the following criteria:

- Measurement method checking: testing the correct implementation of a measurement method is part of a type test, for the end-user the accuracy of the measured values is more important than the underlying measurement method.
- Predictable result: if there is nothing as a reasonable suspicion, we would not recommend doing a test with a predictable result, e.g. a test without applied harmonic distortion will not produce a THDS measurement significantly differing from zero.
- Practical relevance: tests are not practical, if the user cannot understand and interpret the assessment of a test, or if there are just very few use cases. As an example, testing conditions with a voltage of 10 % of the nominal value at - 10° C are not supposed to happen very often in a substation building. And if they do, then other problems than the accuracy of a PQI will be preferential.
- Applicability: tests with certain environmental conditions cannot be reproduced during on-site testing.

Secondly, we rated each individual test considering its duration, complexity and significance to get a final score for the relevance for a routine test. The outcome is a selection with an over-all test duration of about one hour (pure test duration: without assessment, reading through program dialogs, …) and includes at least the tests in Figure 6. At the current state this is only a draft for further discussions.

Template	Topic	Number	Description
6.1	Frequency	A1.2.2	Check measuring uncertainty under reference conditions
6.2	Voltage magnitude	A2.2.2	Check measuring uncertainty under reference conditions
6.3	Flicker	F6.2.1	Check response characteristic for sinusoidal and rectangular voltage changes
6.3	Flicker	F6.2.2	Check response characteristic for sinusoidal and rectangular voltage changes
6.4	Swells, dips	A4.1.2 a)	Check amplitude and duration accuracy for swells and dips
6.4	Swells, dips	A4.1.2 b)	Check amplitude and duration accuracy for swells and dips
6.4	Swells, dips	A4.1.3 a)	Check threshold for swells and dips
6.4	Swells, dips	A4.1.3 b)	Check threshold for swells and dips
6.4	Swells, dips	A4.1.3 c)	Check threshold for swells and dips
6.4	Swells, dips	A4.1.3 d)	Check threshold for swells and dips
6.5	Voltage unbalance	A5.1.4	Check accuracy of voltage unbalance measurement
6.6	Voltage harmonics	A6.2.1	Check measuring uncertainty – single even harmonic
6.6	Voltage harmonics	A6.2.2	Check measuring uncertainty – single odd harmonic
6.6	Voltage harmonics	A6.2.3	Check measuring uncertainty – single high harmonic
6.6	Voltage harmonics	A6.2.4	Check measuring range – low end
6.6	Voltage harmonics	A6.2.5	Check measuring range – high end
6.7	Voltage interharmonics	A7.2.2	Check measuring uncertainty – single low order interharmonic
6.7	Voltage interharmonics	A7.2.3	Check measuring uncertainty – single medium order interharmonic
6.7	Voltage interharmonics	A7.2.4	Check measuring uncertainty – single high order interharmonic
6.7	Voltage interharmonics	A7.2.5	Check measuring range – low end
6.7	Voltage interharmonics	A7.2.6	Check measuring range – high end
6.8	MSV	A8.2.1 a)	Check measuring uncertainty under reference conditions
6.8	MSV	A8.2.2 a)	Check measuring uncertainty under reference conditions
6.8	MSV	A8.2.3 a)	Check measuring uncertainty under reference conditions
6.13	RVC	A13.4.1	Check correct detection of RVC in a polyphase system
6.14	Current magnitude	A14.2.2	Check measuring uncertainty under reference conditions
6.15	Current harmonics	A15.2.1	Check measuring uncertainty – single even harmonic
6.15	Current harmonics	A15.2.2	Check measuring uncertainty – single odd harmonic
6.15	Current harmonics	A15.2.3	Check measuring uncertainty – single high harmonic
6.15	Current harmonics	A15.2.4	Check measuring range – low end
6.15	Current harmonics	A15.2.5	Check measuring range – high end
6.16	Current interharmonics	A16.2.2	Check measuring uncertainty – single low order interharmonic
6.16	Current interharmonics	A16.2.3	Check measuring uncertainty – single medium order interharmonic
6.16	Current interharmonics	A16.2.4	Check measuring uncertainty – single high order interharmonic
6.16	Current interharmonics	A16.2.5	Check measuring range – low end
6.16	Current interharmonics	A16.2.6	Check measuring range – high end
6.17	Current unbalance	A17.1.5	Check accuracy of current unbalance measurement

Figure 6: Selection of tests for PQI routine testing from IEC 62586-2.

6 Summary and Next Steps

About 250 single tests for power quality instrument testing are implemented in 17 test templates, created with focus on clarity, applicability and user-friendliness. Together with a user manual of 90 pages this shall make it possible for non-PQ-experts to execute all kind of tests for PQIs, listed in IEC 62586-2 and in accordance with IEC 61000-4-30.

Additionally, a draft for a future routine testing of PQIs is introduced. It especially includes tests, where the result and assessment are meaningful and important for end-users, as utilities or industry.

In a next step the concept of a routine test will be developed further. In a scientific way the current selection of tests shall be justified and adjusted. For practical verification at site we are looking for partners to ensure that the selected test cases are suitable for execution at site and that they provide the desired results about functionality and accuracy of the PQI in use.

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