Power Quality Instruments (PQI): An Overview

by Chris Ailey, B.Eng.,
Verification & Validation Architect, Schneider Electric

Executive summary

In today's proliferation of renewable and distributed electricity generation sites, there is an increasing need to ***quantify the quality*** of the power flowing throughout the grid. This increasingly necessary function is most consistently performed by a Power Quality Instrument (PQI). A PQI, by definition, adheres to the plethora of requirements outlined by the IEC 62586-1 harmonized product standard. There is a wide spectrum of power quality (PQ) meters available on the market today, however only a few of them are suitable for measuring grid power quality. This paper will help discern which of these meters can be validated as a PQI.

Introduction

Electrical distribution systems can be accurately described as the most complicated structure man has ever created. Any efforts to modernize this vast system involve an increasing trend towards a distributed and renewable energy generation model[1]. This growing shift away from the legacy of a centralized generation system has fundamentally changed the electrical signatures flowing throughout the system. This change is precipitating an increasing and urgent need for accurate and reliable power quality measurements at more points within the distribution system.

There are numerous Power Quality (PQ) meters available on the market today, but only a select few of these meters conform entirely to the type requirements of the Power Quality Instruments (PQI) harmonized product standard, namely: IEC 62586-1[2].
These PQIs are purpose-built to provide robust grid power quality measurement performance.

PQ measurements – a brief history

The availability of PQ measurements has arisen alongside the digitization of the electricity meter. The majority of digital electricity meters produced today can calculate and report on some kind of PQ metrics, but these measurements have been found to differ substantially between manufacturers. This is due, in main part, to diverse measurement algorithms being used by different PQ meter manufacturers. The standard IEC 61000-4-30[3] (4-30, verbalized "four-dash-thirty") was created to address this discrepancy by defining a set of measurement methods and algorithms for each of the PQ metrics.

The 4-30 standard was adopted quickly by PQ meter manufacturers, but unfortunately, when it was first released, there was no traceable and repeatable procedure to verify conformance. The result of this was that, although PQ metric discrepancies had ameliorated significantly with the advent of 4-30, there remained significant differences in measured PQ metrics between device manufacturers.

[1] ENERGY TRANSITION OUTLOOK 2017 - A global and regional forecast of the energy transition to 2050, https://eto.dnvgl.com/2017

[2] IEC 62586-1, Power quality measurement in power supply systems –Part 1: Power quality instruments (PQI), https://webstore.iec.ch/publication/26711

[3] IEC 61000-4-30, Electromagnetic compatibility (EMC) –Part 4-30: Testing and measurement techniques – Power quality measurement methods, https://webstore.iec.ch/publication/21844

PQI: An instrument for the PQ age

The lack of a standard process to verify the implementation of 4-30 on a PQ meter was one of the main impetuses for the development of the IEC 62586 series of standards.

Part 1, namely IEC 62586-1, was constructed to define a comprehensive PQ device product standard, coined within as **PQIs**. The standard outlines safety, electromagnetic compatibility (EMC), climatic, and mechanical requirements, and refers to IEC 62586-2 for functional aspects. These requirements serve to ensure the instrument's robustness will be suitable for its installation within the severe environments of a power station or substation.

Part 2, IEC 62586-2[4], defines the functional tests cited in the first part of the series. These tests are intended to comprehensively verify the PQ measurement methods outlined in 4-30. This chapter was established to provide traceable and repeatable procedures to verify the compliance of each PQ metric outlined in 4-30. This firstly addresses the main shortcoming of 4-30 and ensures better method adherence between PQ meter manufacturers. Additionally, the standard allows regulatory laboratories adhering to ISO/IEC 17025[5] to issue conformance reports and certificates according to IEC 62586-1 or IEC 62586-2 (with compliance to IEC 62586-2 meaning compliance to IEC 61000-4-30). The latter provides PQ meter manufacturers a way to provide internationally recognized compliance for the entire scope of PQI requirements.

To help ensure accurate PQ metrics in the harsh installation environment of a power station or substation, a number of electromagnetic compatibility (EMC) and influence quantity tests were also added to the scope of the IEC 62586 series.

The first chapter's EMC requirements, found in IEC 61000-6-5[6], define the immunity levels which overlap with the expected threat levels to be found in a power station or substation environment. Critically for PQI consistency, this chapter also defines the performance criteria for the continuous phenomena immunity tests.

The second chapter adds singular 'influence quantity tests' for voltage, frequency, harmonics, temperature and auxiliary power supply voltage. All of these influence quantity tests are over and above the base requirements found in 4-30.

With the introduction of the 62586 series of standards, PQ meter manufacturers can now provide internationally recognized certificates for up to three levels of nested conformance:

1. **IEC 61000-4-30** (using the methods outlined in 62586-2)
2. **IEC 62586-2** (covers 4-30 + additional influence tests)
3. **IEC 62586-1 & 62586-2** (required for the PQI-A or PQI-S designation)

The next section provides an overview of the scope for each of these standards and then, in turn, there is an explanation of how the standards overlap and nest within one another.

---

[4] IEC 62586-2, Power quality measurement in power supply systems – Part 2: Functional tests and uncertainty requirements, https://webstore.iec.ch/publication/29675

[5] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, https://www.iso.org/standard/66912.html

[6] IEC 61000-6-5, Electromagnetic compatibility (EMC) – Part 6-5: Generic standards – Immunity for equipment used in power station and substation environment, https://webstore.iec.ch/publication/23146

61000-4-30: The base standard

The IEC 61000-4-30 standard created to address the non-standard power quality metric dilemma constitutes the measurements' base for the PQI. The 4-30 standard defines both Class A and Class S performance categories (**Table 1**). The scope of the standard includes requirements for:

- Measurement Method
- Uncertainty
- Measurement Range
- Influence quantity range
- Aggregation
- Flagging concept

Table 1

(partially shown) excerpt from IEC 61000-4-30 provides a good summary of the requirements for each of the power metrics

Subclause and parameter	Class	Measurement method	Uncertainty	Measuring range[a]	Influence quantity range[b]	Aggregation method
5.1 Frequency	A	See 5.1.1	±10 mHz	42,5 Hz to 57,5 Hz, 51 Hz to 69 Hz	IEC 62586-2	N/R
	S	See 5.1.1	±50 mHz	42,5 Hz to 57,5 Hz, 51 Hz to 69 Hz	IEC 62586-2	N/R
5.2 Magnitude of the supply	A	See 5.2.1	±0,1 % U_{din}	10 %to150 % U_{din}	IEC 62586-2	See 4.4 and 4.5
	S	See 5.2.1	±0,5 % of U_{din}	20 %to120 % U_{din}	IEC 62586-2	See 4.4 and 4.5
5.3	A	IEC61000-4-15	IEC 61000-4-15	0,2 P_{st} to 10,0 P_{st}	IEC 62586-2	IEC 61000-4-15
	S	IEC	See 5.3.2	4,0 P_{st}	IEC 6	C 61000-4-15
5.8 Voltage harmonics		See 5.8.1	Class I	10 % to of Class 3 o IEC 61000-2-4	C 62586-2	See 4. .5
	S	See 5.8.1	200 % of IEC 61000-4-7 Class II	10 % to 100 % of Class 3 of IEC 61000-2-4	IEC 62586-2	See 4.4 and 4.5
5.9 Voltage inter-harmonics	A	See 5.9.1	IEC61000-4-7 Class I	10 % to 200 % of Class 3 of IEC 61000-2-4	IEC 62586-2	See 4.4 and 4.5
	S	SBM	SBM	SBM	IEC 62586-2	See 4.4 and 4.5

Note 1: 4-30 allows these metrics to be implemented "à la carte" in the sense that not all metrics are required for a Class A or S designation. The class designation is per metric.

Note 2: 4-30 stipulates, that for each PQ metric, the Class A or S requirements for a specific PQ metric must be met in their entirety for that metric to be considered 4-30 compliant.

The above two notes are crucial points to consider, when scrutinizing a particular meter manufacturer's compliance documentation. To realize one's overall performance expectations it is highly recommended to consider these two points carefully.

Life Is On Schneider Electric

IEC 62586-1: PQI product standard

The IEC 62586-1 product standard outlines the requirements for each of the categories which comprehensively establish a product standard:

- **Safety** – IEC 61010-1
- **EMC** – IEC 61000-6-5
- **Mechanical / Climatic**
- **Functional Tests** – outlined in IEC 62586-2

One of the important 'real world' tests codified in the standard is the PQ metric accuracy performance during the EMC tests. This standard quantifies, in Table 14, the previously undefined, additional permissible errors (APEs) for the PQ metrics during the continuous phenomena EMC tests. Succinctly, the fundamental 150/180 cycle measurements of voltage, current and total harmonic distortion are only permitted to deviate by twice their respective intrinsic uncertainty limits during these tests.

This is a stringent requirement designed to ensure the PQI provides measurement consistency in the presence of the electromagnetic interference (EMI) commonly found in industrial environments.

IEC 62586-2: PQI Functional tests

IEC 62586-2 outlines the functional tests required for each of the IEC 61000-4-30 PQ metrics:

- Power Frequency
- Voltage Magnitude
- Flicker
- Dips, Swells & Interruptions
- Voltage Unbalance
- Voltage Harmonics
- Voltage Inter-harmonics
- Mains signaling
- Flagging
- Clock uncertainty
- Influence quantities
- Rapid voltage changes (RVC)
- Current Magnitude
- Current Harmonics
- Current Inter-harmonics
- Current Unbalance

The standard prescribes 400+ individual test cases and requirements for Class A PQI verification.

These cases provide traceable and repeatable procedures to verify each PQ metric. When performed in their entirety, they provide a comprehensive assessment of a PQ meter's adherence to the measurement methods of 4-30.

As stated previously, compliance for all the PQ metrics is not required for either a Class A or S designation. The class designation itself refers to each individual PQ metric. When examining meter manufacturer compliance documentation, the recommendation is to look for reports where the performance class is specifically itemized per PQ metric (Table 2).

Table 2

Partial excerpt from IEC 61000-4-30 certificate using the methods of IEC 62586-2 from an IEC/ISO 17025 recognized laboratory.

IEC 62586-2 Clause	Parameter	IEC 61000-4-30 class	Comments
6.1 / 7.1	Power frequency	A + S	50 and 60 Hz
6.2 / 7.2	Magnitude of supply voltage	A + S	
6.3 / 7.3	Flicker	A + S	Class F1 230V, 50 Hz / 60 Hz 120V, 50…
6.15 / 7.15	…ic current	A + S	
6.16 / 7.16	Interharmonic currents	A + S	
6.17 / 7.17	Current unbalance	A + S	
8	Calculation of measurement uncertainty and operating uncertainty	A + S	

A : compliance with class A
S : compliance with class S
--- : Not implemented

The tests are performed in accordance with IEC 62586-2 edition 2 (2017).

Table 3

Partial excerpt from a IEC 62586-2 report outlining the tests for voltage harmonics.

IEC 62586-2 Section	IEC 62586-2 Test No.	Requirement	Remarks	Result for class A
6.6.1	A6.1.1	10/12-cycle measurement intervals are gapless and non-overlapping		P
	A6.1.2	10/12-cycle measurements use the harmonic subgroup measurement		P
	A6.1.3	Measurements are made at least up to the 50th order		P
	A6.1.4	THD		P
	A6.1.5	A crest factor of at least 2 is supported by the device		P
	A6.1.6	A properly designed anti-aliasing filter is used on the device		P
		Che… …ring unce… …hig…		
6.6.2.2	A6.3.1	Check influence of frequency on measurement uncertainty		P
	A6.3.2	Check influence of voltage magnitude on measurement uncertainty		P
6.6.4.1	A6.4.1	10/12 cycles with 10 min synchronization		P
6.6.4.2	A6.5.1	150/180-cycle aggregation with 10 min synchronization		P
6.6.4.3	A6.6.1	10 min aggregation		P
6.6.4.4	A6.7.1	2-h aggregation		P

Scope Comparison

In terms of scope coverage, the three standards (IEC 61000-4-30, IEC 62586-2, and IEC 62586-1) have requirements which can be viewed as nested within one another:

Table 3

The three standards together provide a comprehensive definition for a PQI.

Type test	IEC61000-4-30	62586-2	62586-1
IEC61000-4-30 PQ measurements	X	X	X
IEC61000-4-30 Accuracy of PQ measurements	X	X	X
IEC61000-4-30 Mixed influence quantities	X	X	X
IEC61000-4-30 Aggregation and flagging	X	X	X
IEC61000-4-30 Clock drift test	X	X	X
IEC61000-4-30 Influence of voltage transients and fast transients	X	X	X
Standardized (not proprietary) PQ test waveforms and test points		X	X
Single power system influence quantities: voltage magnitude, frequency, harmonics		X	X
Influence of external quantities: temperature, power supply voltage		X	X
Thermal drift of PQ measurements accuracy		X	X
Product safety (IEC 61010-1)			X
Mechanical (IK, IP, shock, vibrations, earthquakes, drop) tests in operation			X
Environmental (cold, dry heat, damp heat, temp, variation, salt mist)			X
EMC emissions (CISPR 32) and immunity (IEC61000-6-5) with performance criteria for PQ metrics during immunity tests			X
Routine (manufacturing) tests: protective bonding, dielectric, voltage uncertainty (100% coverage)			X

IEC 61000-4-30 defines the set of measurement methods for PQ meters.

IEC 62586-2 builds upon the base of 4-30 and provides the essential verification procedures for the measurement methods. To state it simply, compliance to IEC 62586-2 means compliance to IEC 61000-4-30 and more.

IEC 62586-1 encompasses the scope of these previous two standards and adds the critical safety, EMC and environmental requirements. Together, these three standards comprehensively define the construction and performance requirements for a PQI.

Conclusion

In the age of an accelerating adoption of distributed energy resources, there is an increasing need to *quantify the quality* of the power being delivered or received. This increasing necessity is most reliably performed by a Power Quality Instrument (PQI).

It is only a certified and recognized PQI which can ensure:

1. Correct PQ measurement methods according to IEC 61000-4-30
2. Accurate PQ measurements during real world EMI influences
3. Overall consistent performance in the harsh power station or substation environment

Amid this evolving energy distribution transformation, PQIs are purpose-built for monitoring the grid PQ for either demand or supply-side applications. They provide accurate and consistent measurements enabling an effective means to monitor the overall PQ for a broad scope of deployments. Whether it’s a simple asset management application or an application with complex contractual obligations, confidently manage the grid PQ in them all, with a PQI.

About the author

Chris AILEY is a Principal Verification & Validation Architect in the metering and power monitoring division at Schneider Electric’s R&D Center in Victoria, British Columbia, Canada. He holds a B. Eng from the University of Victoria with a specialty in control systems and digital signal processing. He is involved in IEC, ANSI and UL standardization activities for electricity metering and power quality.

Acknowledgements

Special thanks to **David TUCKEY, Franck GRUFFAZ, and Piotr PRZYDATEK** for their reviews of this white paper.