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TECHNICAL REPORT

colour inside

Demand side power quality management

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

DEMAND SIDE POWER QUALITY MANAGEMENT

FOREWORD

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IEC TR 63191, which is a Technical Report, has been prepared by IEC technical committee 85: Measuring equipment for electrical and electromagnetic quantities.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
85/640/DTR	85/647/RVDTR

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document 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- withdrawn,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 document using a colour printer.

INTRODUCTION

The effective management of power quality on the demand side (power consumer) is an essential activity to ensure the proper operation of the electrical equipment operating on the consumer site.

While the level of power quality present at the point of supply is generally monitored, and managed by the power provider (utility), the actual level of power disturbances present on the consumer site could be significantly worse and may negatively impact the operation of the electrical equipment. The interaction between these loads and the voltage supply is often the cause of degraded power quality on the demand side.

One effective step in the prevention of the hindrances caused by power quality is the assessment of the level of power quality disturbance present on the demand side. However, proper measurements require adequate planning and understanding of the measurement systems and their results.

This document provides guidance on how to establish, implement, exploit, maintain and improve a demand side power quality monitoring system. This document will also facilitate the tailoring of power quality monitoring concepts to the specific site where it will be deployed.

Disturbances in the electrical energy can have an important impact on the equipment, processes, organization's activities and environment. Some electrical installations (industrial sites, data centres, hospitals, etc.) are particularly impacted by the poor quality of electrical energy.

The quality of the electrical energy has different origins, impacts and measurement indicators on the supply side and on the demand side – see Figure 1 presenting an overview of the electrical network from generation (supply side) to consumer (demand side).

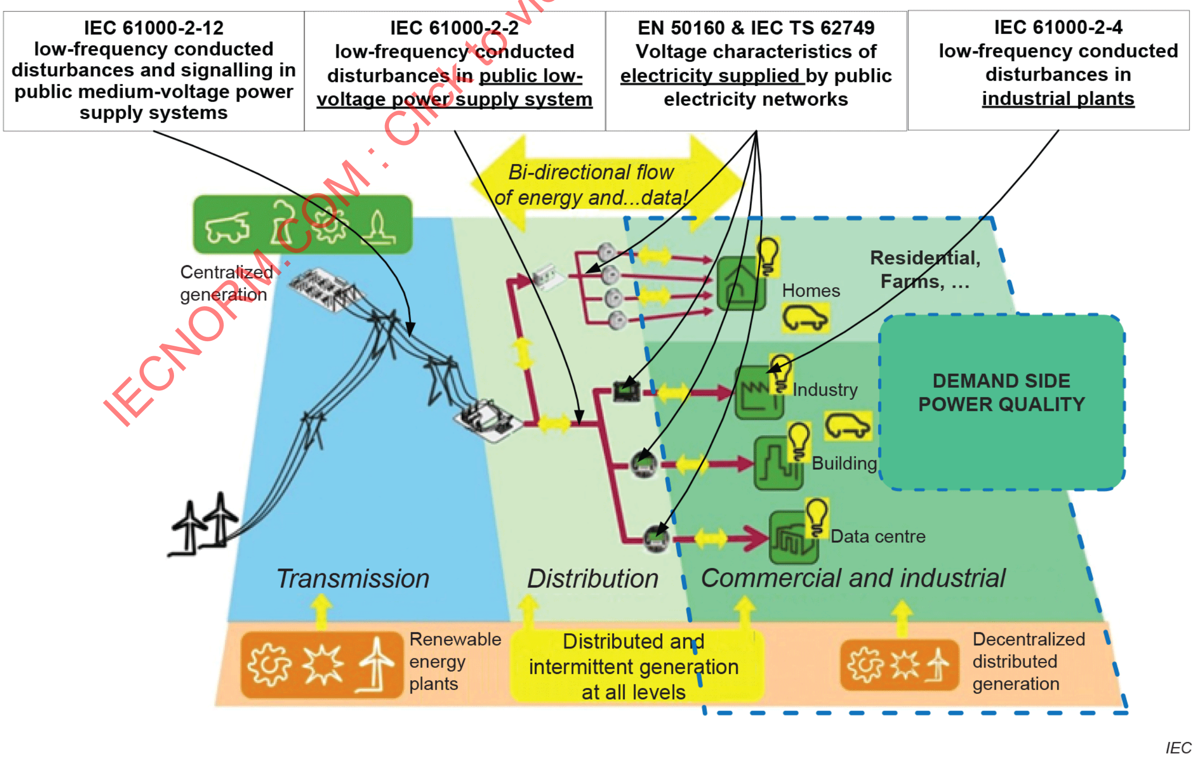


Figure 1 – Overview of electrical distribution system from supply side to demand side

While documents such as IEC TS 62749 or EN 50160 define the voltage characteristics provided by a public network (called power quality of the grid), this document gives guidance for qualifying the electrical quality of internal networks including voltage and current disturbances (called demand side power quality).

In this document, power quality on the demand side, related to buildings, industrial and data centres applications is referred to as demand side power quality (DSPQ).

See Annex D for a general statement on demand side power quality.

See Annex E for a discussion about grid evolution.

See Annex F for a list of standards related to demand side power quality.

See Annex G for definition of electrical parameters.

It is recommended that readers possess a minimum knowledge of power quality phenomena.

DEMAND SIDE POWER QUALITY MANAGEMENT

1 Scope

This document specifies recommendations about power quality measurement and assessment within installations.

NOTE 1 Most standards take care of power quality at the delivery point between energy providers and customers.

This document outlines the various phases needed for the establishment of a demand side power quality measurement plan for buildings and industry installations.

NOTE 2 The demand side is defined as the electrical installation, beyond the PCC (point of common coupling), which is under the jurisdiction of facility managers.

Such a power quality measurement plan will enable the optimization of the energy availability and efficiency, improve the assets lifetime and facilitate the resolutions of power quality problems. A power quality measurement plan encompasses the following stages:

- definition of the context, objectives and constraints;
- assessment of the initial power quality situation;
- definition of an action plan for the improvement of the power quality situation;
- implementation of the power quality measuring system;
- exploitation of the measurement system for the improvement of the power quality situation;
- maintenance of the measurement system.

This document will also help facility managers to tailor their measurement plan to the specific needs of the electrical system under their control. It addresses all the disturbances present in such networks, but does not cover the disturbances present in public electrical distribution networks (supply side) as they are governed by specific documents such as EN 50160 and IEC TS 62749.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
demand side
part of the grid where electric energy is consumed by end-use customers within their electric distribution system

3.2
DSPQ
demand side power quality
characteristics of the electric current, voltage and frequencies at a given point in an electric distribution system located on the demand side, evaluated against a set of reference technical parameters

3.3
IPC
in-plant point of coupling
point on a network inside a system or an installation, electrically nearest to a particular load, at which other loads are, or could be, connected

Note 1 to entry: The IPC is usually the point for which electromagnetic compatibility is to be considered.

3.4
PCC
point of common coupling
point of a power supply network, electrically nearest to a particular load, at which other loads are, or may be, connected

3.5
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

3.6
interruption
reduction of the voltage at a point in the electrical system below the interruption threshold

3.7
interruption threshold
voltage magnitude specified for the purpose of detecting the start and the end of a voltage interruption

3.8
voltage dip
voltage sag
temporary reduction of the voltage magnitude at a point in the electrical system below a threshold

Note 1 to entry: Interruptions are a special case of a voltage dip. Post-processing may be used to distinguish between voltage dips and interruptions.

Note 2 to entry: A voltage dip is also referred to as voltage sag. The two terms are considered as interchangeable; however, this document uses only the term "voltage dip".

3.9
voltage swell
temporary increase of the voltage magnitude at a point in the electrical system above a threshold

3.10
voltage unbalance
condition in a polyphase system in which the RMS values of the line voltages (fundamental component), and/or the phase angles between consecutive line voltages, are not all equal

Note 1 to entry: The degree of the inequality is usually expressed as the ratios of the negative- and zero-sequence components to the positive-sequence component.

Note 2 to entry: In this document, voltage unbalance is considered in relation to 3-phase systems.

[SOURCE: IEC 60050-161:1990, 161-08-09, modified – "phase voltages" has been replaced with "line voltages (fundamental component)", "consecutive phases" has been replaced with "consecutive line voltages" and the notes have been added.]

3.11
transient overvoltage
short-duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

3.12
power quality
PQ
characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters

Note 1 to entry: These parameters might, in some cases, relate to the compatibility between electricity supplied on a network and the loads connected to that network.

3.13
mesh
group of electrical equipment powered from one or more circuits of the electrical installation for one or more zones including one or more services for the purpose of electrical energy efficiency or demand side power quality

[SOURCE: IEC 60364-8-1:2014, 3.1.8, modified – "or demand side power quality" has been added.]

3.14
supraharmonics
disturbances in the range 2 kHz to 150 kHz

3.15
power metering and monitoring device
PMD
combination in one or more devices of several functional modules dedicated to metering and monitoring electrical parameters in energy distribution systems or electrical installations, used for applications such as energy efficiency, power monitoring and network performance

Note 1 to entry: Under the generic term "monitoring" are also included functions of recording, alarm management, etc.

Note 2 to entry: These devices may include demand side quality functions for monitoring inside commercial/industrial installations.

[SOURCE: IEC 61557-12:2007, modified – In the term and definition, "measuring" has been replaced with "metering".]

3.16
power quality instrument
PQI
instrument whose main function is to measure, record and possibly monitor power quality parameters in power supply systems, and whose measuring methods (class A or class S) are defined in IEC 61000-4-30

[SOURCE: IEC 62586-1:2017, 3.1.1]

3.17
total harmonic ratio
total harmonic distortion
THD
ratio of the RMS value of the harmonic content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

Note 1 to entry: The total harmonic ratio depends on the choice of the fundamental component. If it is not clear from the context which one is used an indication should be given.

Note 2 to entry: The total harmonic ratio may be restricted to a certain harmonic order. This is to be stated.

[SOURCE: IEC 60050-551:2001, 551-20-13]

4 Phases of a measurement plan

4.1 Six-phase measurement plan

Clause 4 defines the recommendations for the design and implementation of a demand side power quality measurement plan for an organization.

The plan describes the methodology to put in place a measurement system to monitor the installation from defining the context to maintaining the measurement system (see Figure 2).

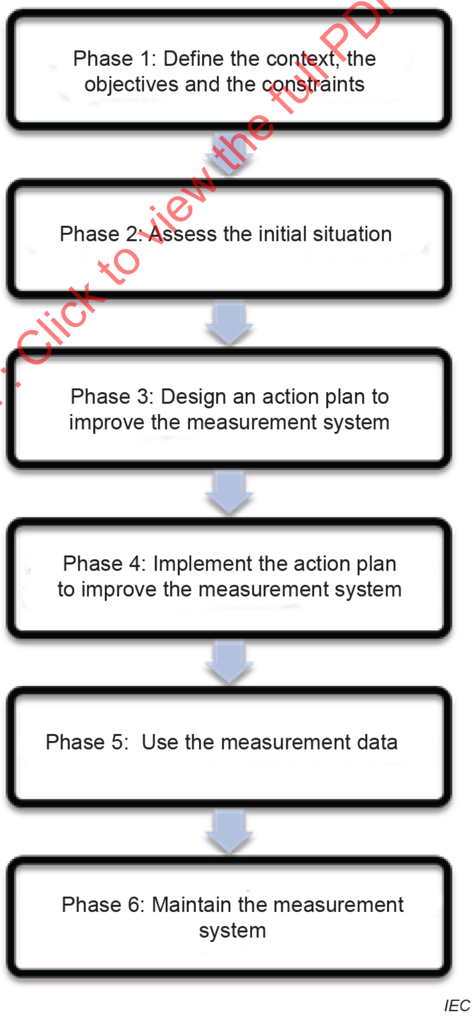


Figure 2 – Six-phase measurement plan

4.2 Phase 1: Define the context, the objectives and the constraints

4.2.1 Goal of phase 1

- Ensure that the motivations, implications and objectives of the organization are clearly defined.
- Ensure that the organizational, technical and financial context will allow the creation and maintenance of a demand side power quality (DSPQ) improvement plan.

4.2.2 Context of the DSPQ improvement plan

Today, an organization wishing to deploy a DSPQ improvement plan faces a number of obstacles, including:

- the design of the plan, defining its content and its boundaries according to the needs and targeted objective;
- the evaluation of the cost/benefits of implementing the plan, supporting the decision;
- the technical difficulties associated with the implementation of the plan.

4.2.3 Motivations of the organization

Mainly to increase its economic competitiveness, quality of services and data security, the organization may design its DSPQ improvement plan according to its objectives, for example:

- ensure the energy availability by minimizing the risk of unwanted tripping and black out;
- avoid supplier penalties;
- avoid deterioration of materials and reduction of their lifetime;
- improve the energy efficiency of installations.

4.2.4 Boundaries of the DSPQ improvement plan

The organization defines the boundaries of the DSPQ improvement plan, and more specifically the sites, the zones, the relevant sources and loads.

See Annex A.

4.2.5 Stakeholders of the plan

The organization may identify the specific needs of each type of user of a DSPQ improvement plan which are as follows.

- Senior management: defines the organization objectives relative to energy management in general and energy measurement in particular, including the budget and priorities.
- Technical director: allocates the resources within the facility and reports on the results. The technical director is capable of evaluating the targeted objectives and those actually achieved, in both energy performance and financial terms.
- Operating and maintenance personnel: tasked with using the measurement system to check and ensure efficient operation by taking corrective measures in the event of deviations in energy performance, by eliminating waste and performing preventive maintenance to reduce deterioration in energy performance. The operating and maintenance personnel can use the measurement system for the process or the equipment under their responsibility.
- Energy manager: provides expertise related to energy management, at site or organizational level. The DSPQ improvement plan is one of the tools the energy manager uses to implement an efficient energy management system. The energy manager is responsible for making sure the scope of measured data is consistent with energy management objectives.

- Installers and system integrators: are responsible for the setup of the measurement and monitoring system. They need to make sure the measurement system is working as expected by the DSPQ improvement plan. They may be internal or external.
- Other external stakeholders: these users can include regulating organizations, service providers, customers, suppliers, architects, facility managers or other organizations.

4.2.6 Budget

The organization defines the budget allocated to the DSPQ improvement plan according to its objectives.

4.2.7 Planning

The DSPQ improvement plan may be implemented in phases according to priorities in order to meet the organization's budgetary constraints.

The organization puts in place a schedule for the implementation of the DSPQ improvement plan. It may indicate the most important milestones of the project.

4.2.8 Resources

The organization identifies the human and material resources necessary for the various phases in the implementation of the DSPQ improvement plan:

- study;
- installation;
- measurement;
- acquisition system or resources necessary for manual reading if necessary;
- processing and interpretation of power quality data consolidation and presentation of data;

  NOTE An external service provider can be necessary to achieve this task.
- maintenance.

The organization clearly identifies a person responsible for the DSPQ improvement plan and ensures that the person is competent and available.

The organization should identify and verify the skills necessary for the application of the DSPQ improvement plan by its personnel or its service providers.

4.2.9 Levels of the measurement system

The organization assesses the appropriateness of its measurement system linked to the DSPQ improvement plan with respect to its needs. The six assessment criteria are:

- the ability to quantify the energy quality by site, by zone or by source and relevant loads;
- the ability to take readings from the quality points at regular intervals;
- the ability to quantify the influencing factors that affect the DSPQ;
- the ability to monitor the installation;
- the ability to view, understand and analyse the DSPQ.

4.2.10 Deliverables for phase 1

The organization provides a note summarizing its objectives and its constraints, the organizational structure adopted and the implementation schedule and budgets allocated to the DSPQ improvement plan.

4.3 Phase 2: Assess the initial situation

4.3.1 Goal of phase 2

- Gather the needs and identify the data to be collected.
- Establish a technical inventory (the available data and equipment).

4.3.2 Preliminary analysis

The organization defines the initial level of power quality by analysing:

- its existing measurement system;
- the energy invoices (for supplier penalties) and contracts;
- the deliverables of a power quality or energy audit;
- electrical mapping and characteristics of the installation and equipment;
- site specifications (use, architecture, neighbourhood, etc.).

4.3.3 Critical and disruptive loads

The organization identifies the critical and disruptive loads relating to power quality, such as:

- power conversion equipment;
- motors starters;
- IT equipment;
- welders;
- switching equipment.

4.3.4 Zones

The organization determines the relevant zones relating to disruptive loads:

- workshops, production lines;
- offices, IT rooms.

4.3.5 Relevant variables

The organization identifies the factors influencing the DSPQ:

- quantity of disruptive equipment;
- quality of the energy delivered by utilities;

  NOTE In Europe, utilities deliver electrical energy according to the quality level defined in EN 50160.
- type of system used (TT, TN, etc.);
- local production of energy;
- disruptive neighbourhoods sites.

According to these factors, the organization has to monitor and analyse the relevant variable. Power quality variables and their impact are defined in Clause 5, especially under the different “Key parameters to measure” subclauses.

4.3.6 Existing measuring devices

The organization draws up an inventory of the existing measuring devices for each installation.

Equipment should comply with their product standard, such as:

- power quality instruments (PQI): IEC 62586-1;

- power metering and monitoring devices (PMD): IEC 61557-12.

NOTE Devices providing measuring functions which comply with IEC 61000-4-30 and tested in accordance with IEC 62586-2 provide matching results (class A or class S).

4.3.7 Data reading and storage

For each quantity measured, the organization determines the reading (automatic or manual) and storage aids already used by the installation. The organization should analyse the appropriateness of the acquisition system (choice and coherence of reading frequencies between the measuring devices) and of storage in relation to its objectives, in accordance with Table 1.

Table 1 – Example of overview of the readings and storage carried out

Measuring point	Location	Measured parameter	Reading method (manual / automatic)	Measurement frequency	For PQI class: class A or class S For PMD type: performance class	Repository system (e.g. spreadsheet, database)
PQI N°1						
PQI N°2						
PMD N°1						
…						

The organization should pay attention to the quality of the data and establish criteria to evaluate the quality of the data.

4.3.8 Deliverables for phase 2

The organization should establish a mapping of the existing installations within the analysis perimeter, identifying the data acquisition and utilization systems. The organization should provide an analysis of the defective elements on the DSPQ or elements that needs supplementing with respect to its objectives.

4.4 Phase 3: Design an action plan to improve the measurement system

4.4.1 Goal of phase 3

Define the actions to undertake under the DSPQ improvement plan to achieve the organization's objectives.

4.4.2 Proposal of improvement actions

To achieve its objectives, the organization implements actions aiming to improve the DSPQ.

To measure the relevant variables, power quality events need long term analysis, so it is recommended to use fixed installed equipment. However, for short periods of time on a targeted zone, portative equipment can be used to analyse the power quality.

Equipment should comply with their product standard, such as:

- power quality instruments (PQI): IEC 62586-1 and IEC 62586-2;
- performance measuring and monitoring devices (PMD): IEC 61557-12.

NOTE Devices providing measuring functions which comply with IEC 61000-4-30 and tested in accordance with IEC 62586-2 provide matching results (class A or class S).

Some guidance to improve DSPQ is given in Clause 5.

4.4.3 Prioritize the actions

One of the proposed actions is to prioritize the installation of measuring equipment on disruptive equipment (if requested by mitigation measures defined in Clause 5).

Annex B provides the state of the art related to disturbance levels on the DSPQ. The organization should use Annex B to define, on the relevant identified variables, the different levels of quality (low disturbance, medium disturbance or high disturbance).

According to these levels, Annex B provides the state of the art related to disturbance levels according to profiles. Thus, it is possible to determine which variables and factors are the most important to treat and prioritize actions accordingly.

4.4.4 Periodic review of the action plan

The organization can, depending on its objectives, priorities and overall budget, define a plan of actions that is graduated over time.

The organization conducts a periodic review of its plan of actions and readjusts it according to the objectives and the results obtained. This review can be carried out as part of the energy management system review.

4.4.5 Deliverables for phase 3

The organization establishes a DSPQ improvement plan with identified actions, implementation priorities, time-frame and agenda.

4.5 Phase 4: Implement the action plan to improve the measurement system

4.5.1 Goal of phase 4

- Ensure the implementation of actions according to the planning and dedicated resources.
- Respect the state of the art regarding equipment installation.

4.5.2 Documentation related to measurement equipment implementation

Manufacturer's documentation has to be read, followed and stored for further use.

Certificates for measurement equipment and for periodical verification are recommended.

4.5.3 Installation and commissioning of measurement equipment

Installations rules in the manufacturer's documentation and installation standards should be followed.

Some equipment needs to be installed and commissioned by the installer or the manufacturer. In this case, the cost of installation has to be taken into account in the budget allocation (in case mitigation measures defined in Clause 5 request installation of devices).

4.5.4 Deliverables for phase 4

Report on the installation (wiring, sensors implementation, etc.) and functioning (sensor ratio configuration, phases ordering, etc.) of the measuring equipment.

4.6 Phase 5: Use the measurement data

4.6.1 Goal of phase 5

- Check the relevance of the implemented actions aiming to improve the DSPQ.
- Identify new actions of DSPQ improvement.
- Identify new factors or sources of disturbance of the DSPQ.

4.6.2 Storage of power quality data

The measurement data should be stored, so that it can be retrieved and used easily. The frequency and method of uploading to the database (manual or automatic) should be appropriate for the users' needs (including performance) and the targets of the organization.

The organization should define a minimum retention period for the data, in accordance with legal or other requirements. The organization should define a maximum retention period, a backup strategy and an aggregation strategy for the data, to ensure the long-term usability of the system.

The organization should check the quality of the measurement data provided by the measurement system. When corrections are made to the measurements, the organization should identify that they have undergone a retrospective modification (date and nature of change, possibly the modification originator).

4.6.3 Analysis of power quality data

Classify the power quality measurements according to Annex B.

It is important to determine relevant indicators between initial and measured data in order to define the relevance of implemented actions.

It is important to ensure that the analysis of power quality data is achieved by competent people.

If no internal competencies exist, power quality data could be analysed by external experts or by the equipment manufacturers.

4.6.4 Dissemination and protection of power quality data

This data has to be shared with interested and skilled people inside the organization.

4.6.5 Deliverables for phase 5

Report power quality measurement in order to establish an improvement plan.

4.7 Phase 6: Maintain the measurement system

4.7.1 Goal of phase 6

Ensure the sustainability and the accuracy of the measurement system.

4.7.2 Verification of the measurement system

The measurement system should be verified in accordance with the recommendations given by the manufacturer of the equipment.

4.7.3 Metrological maintenance and monitoring

Instruments need to be verified according to the manufacturer's specifications.

4.7.4 Deliverables for phase 6

Maintenance planning for the measurement devices and maintenance report.

Devices firmwares and softwares can be updated.

The system has to stay operational and calibrated to ensure the power quality data collected are reliable.

5 Demand side power quality disturbances and their impact

5.1 General

Clause 5 intends to provide origin, effect, mitigation and key parameters related to power quality disturbances, in AC distribution networks, on the demand side.

Further information is provided in Annex C.

See Table 2, Table 3 and Table 4.

An attempt to provide similar information for DC networks is provided in Annex H.

Table 2 – Classification of PQ phenomena

Continuous phenomena
• Long-term frequency variations
• Long-term voltage variations
• Voltage/current unbalance
• Flicker
• Voltage/current harmonics and interharmonics, including supraharmonics
Events
• Supply voltage dips and interruptions
• Supply voltage swells
• Transient overvoltage
• Rapid voltage changes

Table 3 – Origins of PQ problems

Supply side	**Demand side**
Frequency variations	Current harmonics and interharmonics
Voltage variations	Current unbalance
Voltage harmonics and interharmonics	Reactive power
Voltage unbalance	Neutral currents
	Rapid voltage changes
Supply voltage dips, swells, interruptions	
Flicker	
Voltage transients	

Table 4 – Impacts of PQ problems on consumers, manufacturers and utilities

Financial losses due to	Interruption of processes
	Equipment damage and/or aging
	Production loss
	Waste of raw material
	Loss of data
	Increased losses in electrical equipment and distribution system
	Disturbance and interference to electronics appliances and communication networks
	Malfunctioning of protection relays

5.2 Frequency deviation

5.2.1 Origins

Frequency deviation is caused by an unbalance between the generated capacity and the connected loads.

Frequency deviations are limited in amplitude in stable interconnected utility grid.

However, it is possible to experience significant frequency deviations in case of poor power infrastructure or when the sites have their own local power production and operate independently from the grid.

The frequency deviation results from the source (generator or inverter in case of renewable energy production) and its control system.

5.2.2 Effects

5.2.2.1 Effects on motors

Three-phase induction motors are designed to operate most efficiently at their rated frequency. A significant frequency drift may cause a motor to run faster or slower to match the frequency of the input power. This would cause the motor to run inefficiently and/or lead to overheating and motor attrition.

5.2.2.2 Effects on IT equipment

IT equipment is frequency tolerant, and generally not affected by minor frequency shifts. However, significant frequency deviation may lead to erratic operation, data loss and system crashes.

5.2.2.3 Effects on other equipment

Important frequency variations may affect the operation of other equipment within the installation such as transformers, capacitors and active filters.

5.2.3 Possible mitigation measures

To mitigate frequency deviation, all power sources and their control systems should be assessed, and then corrected.

5.2.4 Key parameters to measure

Power frequency.

5.3 Magnitude of supply voltage: deviation, underdeviations, overdeviations

5.3.1 Origins

The values of nominal voltage specified in IEC 60038 are mainly based on the historical development of electrical supply systems throughout the world, since these values turned out to be the most common ones, and have achieved worldwide recognition. The voltage ranges mentioned in IEC 60038 have been recognized to be the most appropriate ones as a basis for design and testing of electrical equipment and systems. As part of the energy transition, there is an increasing supply of renewable energy at all voltage levels. When feeding at the highest voltage level (e.g. by large wind farms), this occasionally caused bottlenecks of network capacity, but voltage control is more difficult in particular by feed-in medium and low voltage networks. These networks have been designed as pure distribution networks and essential feeds were not provided. The main problem is the fluctuating nature of the feeds of wind turbines. Each country has requirements on nominal values and tolerances. IEC 61010-1:2010, Annex I provides relevant information on most common mains systems.

5.3.2 Effects

5.3.2.1 General effects

In general, the lifetime of products will decrease with voltage overdeviations.

5.3.2.2 Effects on motors

Deviations above or below a motor's rated nameplate voltage will have a detrimental effect on induction motors. Figure 3 illustrates the effects of typical motor characteristics as a motor's terminal voltage is increased or decreased from its rated voltage.

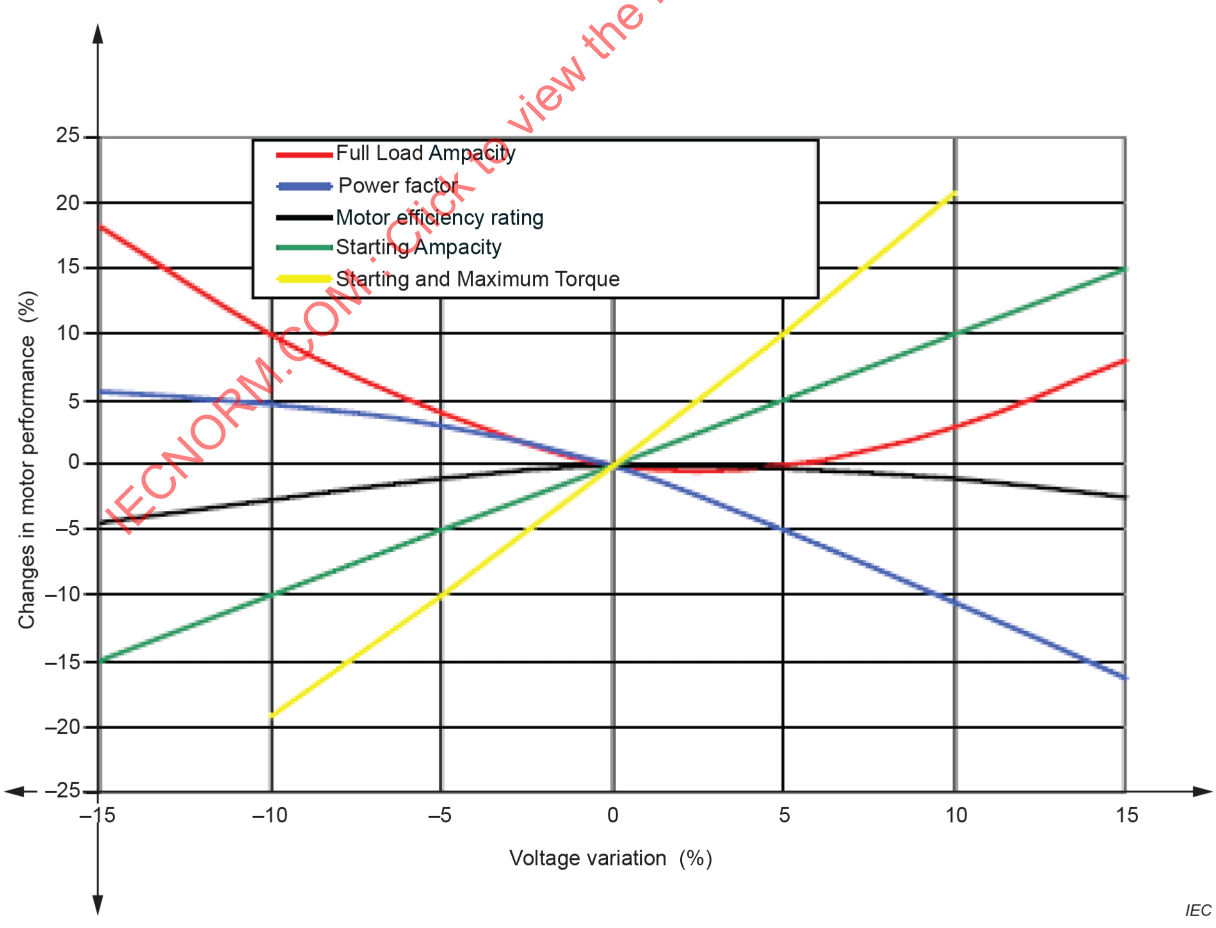


Figure 3 – Effects of voltage deviation on a motor

One consequence of deviating from the rated voltage is an increase in the motor's current. Operating outside a motor's required voltage range for prolonged periods generates heat in the motor's core. This can damage the motor's insulation.

The torque at a given speed is proportional to the square of the applied voltage. Thus, if the stator's voltage decreases by 5 %, the torque at every speed will decrease by approximately 10 %. If the reduced torque is inadequate to drive the load, attempting to start an induction motor during low-voltage conditions may cause the motor to stall. Figure 3 also illustrates how voltage deviations can affect such characteristics as the efficiency and power factor of the motor. Using a motor that is not intended for an application, or is not provided a suitable terminal voltage, will likely result in elevated temperatures, ultimately shortening the motor's life.

IEC 60034-1 provides guidelines for the operating voltages at an induction motor's terminals. Some standards specify a voltage range of ±10 % of a motor's nameplate rating, and IEC 60034-1 specifies a voltage range of ±5 % of a motor's nameplate rating. In both cases, it is assumed that the electrical system is operating at the motor's rated frequency.

Most monitoring devices can detect voltage deviations and trigger an alarm. In some monitoring devices, it is possible to set up multiple alarms with a unique priority level for each alarm. The user can be notified by a lower priority alarm when a threshold is being approached and by a higher priority alarm when that threshold is exceeded.

5.3.2.3 Effects on lighting

The lifetime of a light bulb will be decreased with overdeviation.

5.3.3 Possible mitigation measures

If equipment is installed that is sensitive to over/underdeviation, use a voltage stabilizer.

If supply voltage is permanently under deviated, check wiring of the installation.

5.3.4 Key parameters to measure

The key parameter for voltage magnitude measurement is voltage measurement (RMS value).

Measurement over a 10 min time period and 2 h time period may provide the best information.

5.4 Flicker

5.4.1 Origins

Flicker describes the subjective impression of light density fluctuations, caused by fluctuations in the supply voltage.

Flicker is caused by

- start-up or load variation of motors,
- activating and deactivating of large loads,
- welding or arc furnaces,
- pulsed power levels (multicycle control),
- wind turbines,
- magnetic resonance tomography,
- elevators,
- compressors, etc.

5.4.2 Effects

5.4.2.1 Effects on human beings

The foremost effect of voltage fluctuations is lamp flicker. Lamp flicker occurs when the intensity of the light from a lamp varies due to changes in the magnitude of the supply voltage. This changing intensity can create annoyance to the human eye and, as a result, has impacts on the human body ranging from lack of concentration and general feelings of discomfort to epileptic fits.

5.4.3 Possible mitigation measures

Flicker mitigation methods should be based on reducing voltage fluctuations. The effects of voltage fluctuations are dependent on its magnitude and the rate of their occurrence. Mitigation measures are focused on limiting the magnitude of the voltage fluctuations.

Several approaches can be implemented for this purpose.

1) Reducing load power variations, particularly the reactive component.

   Flicker compensation devices such as dynamic voltage stabilizers and/or synchronous machines are installed at the point of connection.

   This is a general term used to describe devices that can control the amount of reactive power absorbed from or injected into the power system. Subsequently, the RMS voltage at the point of connection can be increased or reduced.

   These flicker-mitigating power quality devices include the following:

   - static Var compensators (SVC);
   - thyristor-switched capacitors (TSC);
   - thyristor-controlled reactors (TSR) with fixed capacitor (FC) or switched capacitor (TSC);
   - static synchronous compensator (STATCOM);
   - saturable reactors;
   - dynamic voltage regulator (DVR).

2) Increasing the short-circuit power level (with respect to the load power).

   Common measures implemented to increase the short-circuit power are:

   - connecting the load at a higher nominal voltage level;
   - constructing additional lines to reinforce the existing distribution line;
   - supplying flicker-producing loads through dedicated lines;
   - installing series capacitors;
   - separating fluctuating loads from steady loads (i.e. light or lamps) using separate winding of a 3-winding transformer;
   - increasing the rated power of the transformer serving the fluctuating load.

3) Changing the type of lamps.

5.4.4 Key parameters to measure

P_{ST} (short term flicker severity: 10-minute average value) and P_{LT} (long term flicker severity: 2-hour average value) are the key parameters for flicker evaluation.

5.5 Voltage dips, swells and interruptions

5.5.1 Origins

Voltage events can be caused by:

- faults in the transmission or distribution network,
- faults in the consumer's installation,
- switching of heavy loads or start-up of large motors,
- malfunction in voltage stabilization systems such as UPS, power conditioners, voltage regulators or variable transformers.

5.5.2 Effects

5.5.2.1 General effects

- unscheduled downtime potentially leading to loss of production, material wastages, equipment damage, and even some safety issues;
- malfunction of PLCs, VSDs, PCs;
- tripping of contactors, circuit breakers or protection relays;
- stalling of motors;
- lighting effects.

5.5.2.2 Effects on motors

Voltage dips can affect a motor's operation both directly and indirectly. Voltage dips directly affect a motor by causing a decrease in their torque and speed. Once the fault is cleared, motors draw high reactive currents in an attempt to return to their pre-event speed. The increase in reactive current prolongs the total duration of the voltage dip event.

Voltage dips indirectly affect a motor's operation and reliability through the motor's controls. Magnetic contactors, which open and close a motor's circuit, are susceptible to voltage dip events on the electrical system. Magnetic contactors use solenoid action (via a coil) to open and close a set of contacts, thus opening and closing the motor's circuit.

5.5.3 Possible mitigation measures

Several solutions are possible:

- static UPS;
- flywheel;
- dynamic voltage restorer;
- shunt connected synchronous motor;
- transformerless series injector;
- power conditioner/voltage regulator;
- utility PQ improvement partnership;
- immune loads.

5.5.4 Key parameters to measure

Voltage events are often short, invisible and difficult to catch. Service calls are expensive; it could take a long time to measure and identify the problem with portable instruments. Only continuous measurements with the right instrument guarantee a fast and reliable recording of these disturbances. Monitoring devices need to sample the voltage and current waveforms at a fast enough rate to ensure that all relevant information is captured. Information that is useful in determining the presence of contact bouncing may include the event's magnitude, its respective duration, and any associated high frequency components.

For classification of voltage events, two different approaches are published in EN 50160 and IEC TS 62749 (see Table 5 and Table 6).

Table 5 –Voltage dip/interruption and swell classification according to EN 50160

Residual voltage, U [%]	Duration, t [ms]				
	20 ≤ t ≤ 200	200 < t ≤ 500	500 < t ≤ 1 000	1 000 < t ≤ 5 000	5 000 < t ≤ 60 000
90 > U ≥ 80	CELL A1	CELL A2	CELL A3	CELL A4	CELL A5
80 > U ≥ 70	CELL B1	CELL B2	CELL B3	CELL B4	CELL B5
70 > U ≥ 40	CELL C1	CELL C2	CELL C3	CELL C4	CELL C5
40 > U ≥ 5	CELL D1	CELL D2	CELL D3	CELL D4	CELL D5
5 > U	CELL X1	CELL X2	CELL X3	CELL X4	CELL X5
Swell voltage, U [%]	**Duration, t [ms]**				
	20 ≤ t ≤ 500	500 < t ≤ 5 000	5 000 < t ≤ 60 000		
U ≥ 120	CELL S1	CELL S2	CELL S3		
120 > U ≥ 110	CELL T1	CELL T2	CELL T3		

Table 6 – Voltage event classification according to IEC TS 62749

Residual voltage, U [%]	Duration, t [ms]				
	20 ≤ t ≤ 200	200 < t ≤ 500	500 < t ≤ 1 000	1 000 < t ≤ 5 000	5 000 < t ≤ 60 000
U ≥ 120					
120 > U ≥ 110					
90 > U ≥ 80					
80 > U ≥ 70					
70 > U ≥ 40					
40 > U ≥ 10					
10 > U					
Voltage interruption					

A common and easy to understand graphical representation of voltage events is the ITI curve (see Figure 4).

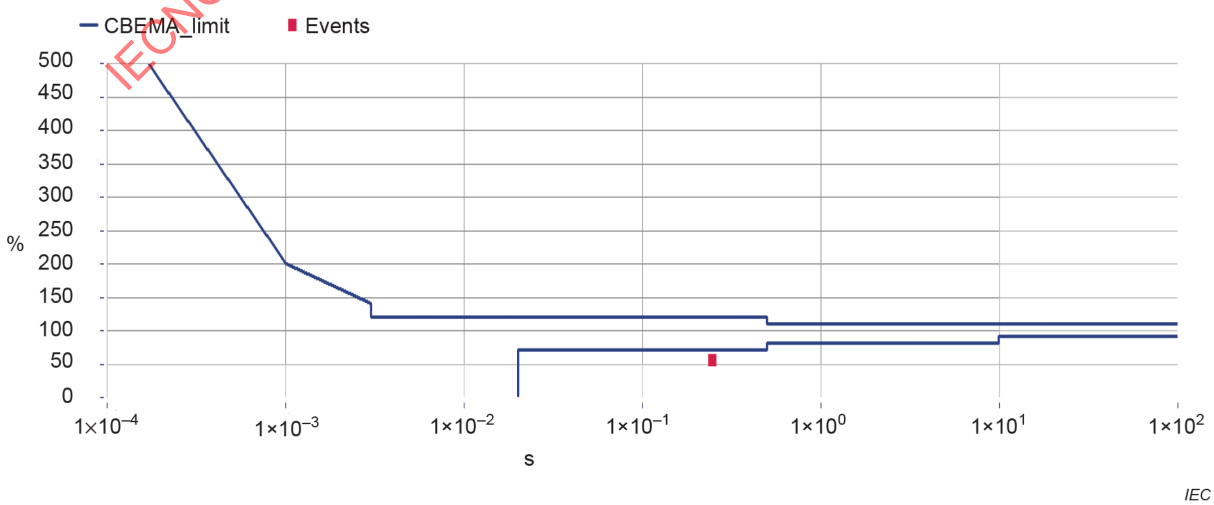


Figure 4 – Visualization of voltage events in modified ITI curve

5.6 Transient overvoltages

5.6.1 General

Ranging from nanoseconds (electrostatic discharges) to a few milliseconds (induced transient surges transmitted by power and telecommunication lines) and up to a few milliseconds maximum (overvoltages due to lightning on building's system protection), overvoltages transmitted to installations by LV power lines can range up to 12 kV in low voltage systems and can cause flashovers and in some cases an arc explosion of hundreds of amperes (A) up to 100 kA typically.

5.6.2 Origins

Origins for transient overvoltages are both outside and inside facilities:

- Origins from outside: lightning strikes on power lines or their direct vicinity, lightning strikes on lightning protection systems (lightning protection of buildings) and switching or electrical incidents on the power distribution network.
- Origins from inside: switching of internal heavy loads (motors, lifts, welders, HVAC, contactors, PFC banks, etc.) or overcurrent protection (breakers, switches, etc.), electrostatic discharges, etc.

5.6.3 Effects

5.6.3.1 General effects

According to studies, transient overvoltages cause up to 30 % of disturbances and electrical damages, ranging from data loss, damages or destruction of equipment, power or production losses, of which 70 % originate from switching of internal loads.

5.6.3.2 Effects on motors and electronics

IEC 61000-2-4 defines a transient overvoltage as an oscillatory or non-oscillatory overvoltage, highly damped and up to a few milliseconds in duration with a rise time from less than 1 µs to a few milliseconds. Transient overvoltages that exceed insulation ratings can stress insulations of all electronic equipment and motors, leading to a gradual or even abrupt breakdown of the dielectric insulation.

Because the inductance of a motor is a natural low-pass filter for the high frequency components associated with transient overvoltage events, the first turn or two of a motor's stator windings absorb the brunt of the transient's energy.

5.6.4 Possible mitigation measures

The panel of mitigation measures is large depending on the kind of installation and the final use of the facility, for example:

- Installation of surge protective devices (SPDs, IEC 61643-11): to mitigate effects of transient overvoltages due to lightning strikes on protection systems of buildings but also from both external and internal switching (e.g. from power contactors).
- Proper design of the electric installations (IEC 60364-4-44:2007 and IEC 60364-4-44:2007/AMD2:2018, Clause 444 and IEC 60364-5-54): EMC design (screened cables, correct cable routing in trunking), correct design of earthings and equipotential bonding.
- Selection of equipment with proper overvoltage categories (the higher the overvoltage category, the better the overvoltage withstand (insulation coordination) and immunity) (overvoltage withstand of electronics between active wires), IEC 60364-4-44:2007 and IEC 60364-4-44:2007/AMD1:2015, Clause 443, IEC 61000-4-5, IEC 61643-12.
- Filters and screenings against electromagnetic and electrostatic discharges.

- Transformers can also help to mitigate surges (screened transformers) or against overvoltages if specially designed for this purpose (equipped with SPDs).
- UPS can also help to mitigate small surges as secondary protection levels or against overvoltages if internally equipped with SPDs.

5.6.5 Key parameters to measure

See transient measurements in IEC 61000-4-30:2015, Clause A.4.

Measuring devices typically use one of two techniques to detect transient overvoltages. The first method, peak detection, can provide the user with information related to a transient overvoltage time of occurrence, magnitude, and duration. The peak detection method is less expensive, but it does not provide a waveform capture of the event.

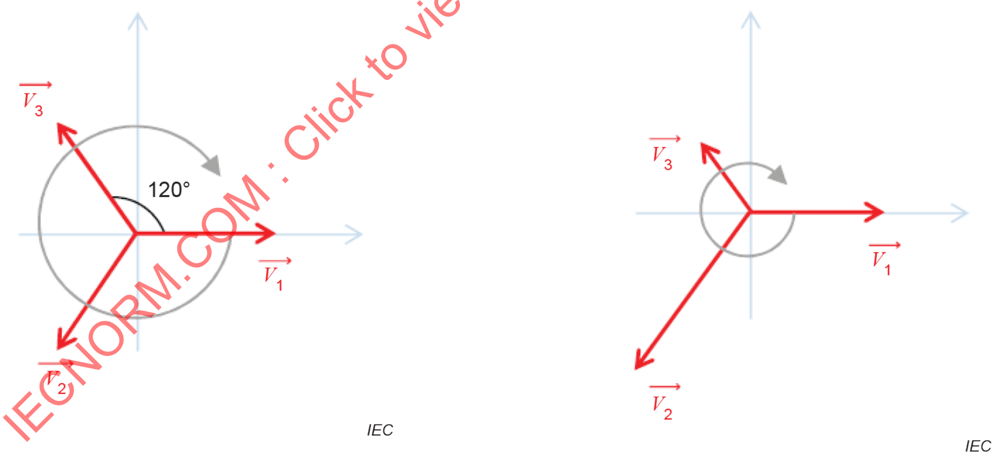
Waveform captures are useful in troubleshooting the source of a transient overvoltage event. The second method can be achieved using a high-speed digital-sampling A/D converter although they are more expensive. Transient overvoltage events have a tendency to attenuate quickly in electrical power systems due to the inductive nature of the system. Therefore, it is advantageous to place the metering device close to the equipment to be monitored for a more precise measurement of the effects of a transient overvoltage event on it.

5.7 Supply voltage unbalance and current unbalance

5.7.1 General

Voltage unbalance is regarded as a power quality problem of significant concern at the electricity distribution level.

See Figure 5.



a) Direct, perfect, symmetrical 3-phase system

b) Asymmetrical 3-phase system characterized by the unbalance of the 3 phases

Figure 5 – Examples of unbalanced systems

It is easy to check that a three-phase system is balanced, with the sum of the voltage vectors $\vec{V}_1 + \vec{V}_2 + \vec{V}_3 = 0$. In the opposite case (unbalanced system), this sum is not equal to zero.

It is practically impossible to eliminate voltage unbalance, but it can be kept under control at both utility and plant level by several practical approaches.

5.7.2 Origins

Unbalance is caused by:

- faulty operation of power factor correction equipment,
- unbalanced or unstable utility supply,
- unevenly distributed single-phase loads on the same power system,
- an open circuit on the distribution system primary.

5.7.3 Effects

Voltage unbalance degrades the performance and life of three-phase equipment, especially of motors. Voltage unbalance at the motor terminals can cause current unbalance higher in proportion than the voltage unbalance itself (typically 6 to 10 times). Unbalanced currents lead to:

- overheating due to negative sequence components that reduces winding insulation life;
- torque variation, vibrations and increased losses resulting in lower efficiency.

In addition, motor controllers and inverters embed components that are sensitive to voltage unbalances.

It is recommended that voltage unbalances at the motor terminals do not exceed 2 %, requiring sometimes an oversizing of the motor.

5.7.4 Possible mitigation measures

Mitigation measures include redistribution of single phase loads, voltage correction capacitors and power conditioners. Protection equipment is recommended for motors against current unbalance bigger than 12 % during more than 10 s.

5.7.5 Key parameters to measure

There are several approaches to calculate the unbalance that applies to voltage or current.

First approach:

The negative sequence unbalance ratio u_2 expressed as a percentage is evaluated by:

$$u_2 = \frac{U_2}{U_1} \times 100\,\% = \frac{\text{negative sequence}}{\text{positive sequence}} \times 100\,\%$$

The zero-sequence unbalance ratio u_0 expressed as a percentage is evaluated by:

$$u_0 = \frac{U_0}{U_1} \times 100\,\% = \frac{\text{zero sequence}}{\text{positive sequence}} \times 100\,\%$$

Second approach:

$$\text{Voltage unbalance} = \frac{\text{Maximum deviation from mean of } \{V_{ab}, V_{bc}, V_{ca}\}}{\text{Mean of } \{V_{ab}, V_{bc}, V_{ca}\}}$$

The voltage unbalance should not exceed 2 %.

5.8 Voltage and current harmonics, inter-harmonics and sub-harmonics

5.8.1 Origins

A difference needs to be made between the 3 kinds of harmonics:

Harmonics: A sinusoidal component of a periodic wave having a frequency that is an integer multiple of the fundamental frequency. Example: 300 Hz is the harmonic rank 6 of a 50 Hz signal, and also the harmonic rank 5 of a 60 Hz signal.

Inter-harmonics: Components with frequencies between two consecutive harmonics or those components whose frequencies are not integer multiples of the fundamental power frequency. Example: 175 Hz is the inter-harmonic rank 3,5 of a 50 Hz signal.

Sub-harmonics: A special subset of inter-harmonics that have frequency values that are less than those of the fundamental frequency. Example: 30 Hz is the sub-harmonic rank 0,6 of a 50 Hz signal.

In the following, the term harmonic may refer to harmonics, inter-harmonics or sub-harmonics.

The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms. Harmonic currents are caused by non-linear loads (e.g. power electronics supply) connected to the distribution system. A load is said to be non-linear when the current it draws does not have the same waveform as the supply voltage. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage.

Typical current waveforms for single-phase non-linear loads are shown in Figure 6 and three-phase non-linear loads in Figure 7.

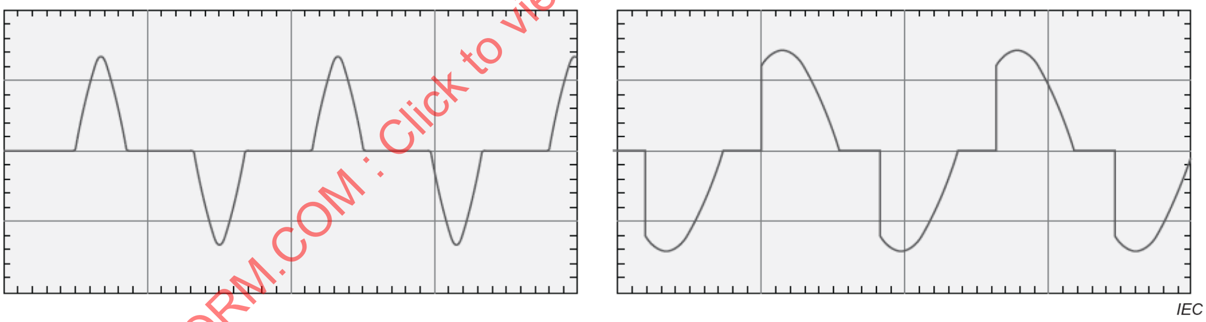


Figure 6 – Typical current waveforms for single-phase non-linear loads

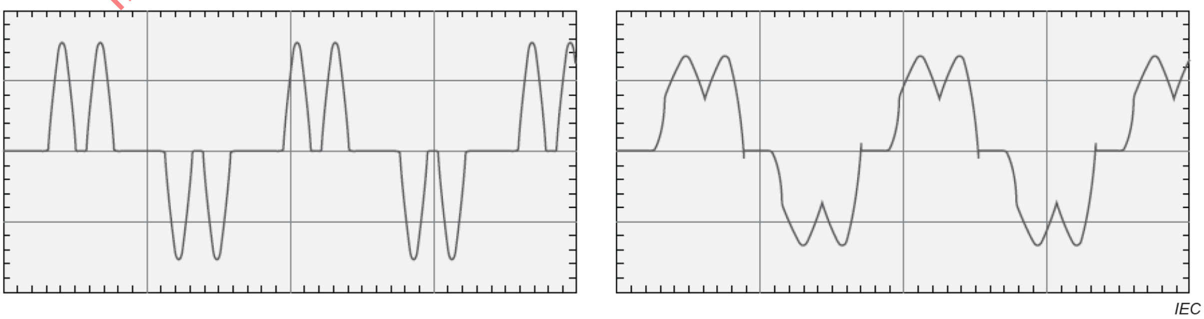


Figure 7 – Typical current waveforms for three-phase non-linear loads

Equipment comprising power electronics circuits are typical non-linear loads. Such loads are increasingly frequent in all industrial, commercial and residential installations and their percentage in overall electrical consumption is growing steadily.

Examples include:

- industrial equipment (welding machines, arc and induction furnaces, battery chargers, etc.);
- variable speed drives for AC or DC motors;
- uninterruptible power supplies;
- office equipment (PCs, printers, servers, etc.);
- household appliances (TV sets, microwave ovens, fluorescent lighting, light dimmers).

5.8.2 Effects

5.8.2.1 General effects

The major consequences of harmonics are the increase of the RMS current in the different circuits and the deterioration of the supply voltage quality. The negative impact may remain un-noticed, but economical results may be compromised:

- increased overloading on the electrical system, thereby limiting useable capacity;
- increased energy losses and demand power and reduction of energy efficiency;
- increased risks of outage;
- overheating of equipment and cables in installation leading to a reduction of equipment lifetime;
- perturbation of some electronic systems.

5.8.2.2 Effects of the harmonic rank 3 and multiples

The accumulation of current harmonics of rank 3 and multiples, leading the circulation of a current in the neutral and PEN conductor, can result in a major safety issue in the main system (fire, high touch voltage, etc.) due to overheating or interruption.

5.8.2.3 Effects on induction motors

Voltage harmonics produce additional eddy currents, hysteresis, and I_2R losses due to the resulting harmonic currents. In a three-phase power system, there are three sets of symmetrical components – positive, negative, and zero sequence – for both voltages and currents. The positive-sequence set is equal in magnitude and 120° apart. The negative-sequence set is also equal in magnitude and 120° apart; however, they are counter-rotational with respect to the positive-sequence components. The zero-sequence set is equal in both magnitude and phase. In a completely balanced (or symmetrical) three-phase system, the fundamental frequency is assumed to be a positive-sequence set (+), with all other sets being relative to it. Thus, the second harmonic would be a negative-sequence set (−), the third harmonic would be a zero-sequence (0). The sequential sets repeat for additional harmonics (i.e. the fourth harmonic is (+), the fifth harmonic is (−), and so on). This is important because different harmonics affect an induction motor differently.

Positive-sequence currents provide positive rotational torque in a motor because they rotate in the same direction as the fundamental frequency, which is also positive sequence.

Negative-sequence currents provide counter-rotational torque in an induction motor (with respect to the fundamental current), and they produce additional heating.

Zero-sequence currents do not directly affect a motor’s torque, but they can produce additional losses in a motor’s core.

NOTE In an unbalanced three-phase system, this model is not valid because each sequential current can produce its own set of sequential voltage drops.

5.8.3 Possible mitigation measures

- AC-Line or DC-link chokes for drives. They are commonly used up to about 500 kW unit power or 1 000 kW total drives power. When a large number of drives are present within an installation, the use of AC-Line or DC-link chokes for each individual drive is recommended. This measure increases the life time of drives and enables use of cost-effective mitigation solutions at installation level, such as active filters.
- Anti-harmonics filter (active or passive).
- Neutral current eliminator (NCE) filter: cancel current harmonics from rank 3 of neutral and balance current between phases.
- Taking into account harmonic pollution characteristics when disruptive equipment is bought.
- Improving the wiring system.
- Adding another transformer.

5.8.4 Key parameters to measure

THD (and possibly individual harmonic components).

The total harmonic distortion *THD* is the usual parameter to evaluate the level of distortion of an alternating signal. The voltage distortion THD_u is usually considered at the installation level while the current distortion THD_i is usually considered at the non-linear equipment level (caused by the system impedance).

System impedance plays an important role in determining the level of voltage distortion, so locating the monitoring device near the load is usually a good practice.

High-end monitoring systems provide a plethora of information about an electrical system's harmonic distortion. This can include total harmonic distortion of voltages and currents, individual harmonic component information, and, in some cases, harmonic power flows.

Measurement of individual harmonics up to rank 25 at least is recommended, while measurement up to rank 40 or 50 might be worthwhile in some cases.

Third harmonic is a safety issue and needs to be measured.

5.8.5 Emerging topic

There is an emerging topic related to disturbances in the range 2 kHz to 150 kHz, caused by power electronics, and it has been shown that it can impact on legal metrology and interfere with PLC communications. At this time, some measurement methods are specified in standards such as CISPR 16 (all parts), IEC 61000-4-30 and IEC 61000-4-7 but their acceptance is still under debate.

5.9 Mains signalling voltage

5.9.1 General

MsV is a kind of harmonics or inter-harmonics.

5.9.2 Origins

This is an intentionally generated signal, coupled in a distribution network.

Limits to mains signalling voltage are given in EN 50065.

5.9.3 Effects

When attenuated by the network, the meter is not able to switch to the relevant tariff.

On the other hand, resonance can occur in the distribution network, leading to a high level of *MsV* (see 5.8).

5.9.4 Possible mitigation measures

Determine where the resonance occurs, or where the signal is swallowed.

5.9.5 Key parameters to measure

MsV.

5.10 Rapid voltage changes

5.10.1 Origins

A rapid voltage change (*RVC*) is the change of the RMS value in-between the thresholds defined for voltage swells and dips.

RVC can be caused by:

- start up of motors,
- normal use of electrical equipment, e.g. in rural areas where the short-circuit power is low,
- transformer inrush,
- variable transformer switching.

5.10.2 Effects

Rapid voltage changes will cause irritation to people because of changes in the illumination intensity. The main effect of *RVC*s is visual discomfort. However, the voltage change in magnitude is usually not significant, thus it will not damage the electrical equipment.

5.10.3 Possible mitigation measures

Mitigation measures can include "point on wave" controlled switching equipment, additional switchgear and reconfiguration and/or re-design of the transmission network up to and including the construction of additional lines or cables.

5.10.4 Key parameters to measure

A rapid voltage change is defined as the change in the RMS value of a voltage signal that moves from a steady state value to a maximum change and then gradually varies and settles at a new level determined by $\Delta U_{\text{steadystate}}$. It is characterized by

- maximum depth ΔU_{max},
- duration (T), and
- steady state value variation $\Delta U_{\text{steadystate}}$ (or ΔU_{ss}).

In order for the event to be classified as an *RVC*, ΔU_{max} should be less than ±10 % of U_{din}. (see Figure 8).

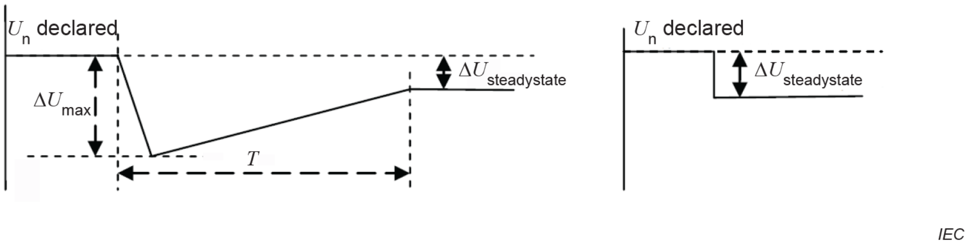


Figure 8 – RVC characterization

It is useful to count the number of *RVC* events per hour, or per day, or both.

A recommendation for the threshold of *RVC* is given in IEC TS 62749. Rapid voltage change indicative values are in the range of 3 % to 5 % of U_{din}.

A limit for *RVC* events is defined in EN 50160:2010/A1:2015, Annex ZA, Deviation 3.17 for Norway only. Rapid voltage changes should be within the following limits at all supply terminals 100 % of the time:

RVCs	**Maximum frequency per 24 h period**	
	0,23 kV ≤ U_N ≤ 35 kV	35 kV < U_N
$\Delta U_{steadystate}$ ≥ 3 %	24	12
ΔU_{max} ≥ 5 %	24	12

5.11 Synthesis of events impacts

See Table 7.

Table 7 – Overview of events and impacts

Event	Potential impact on assets	Potential impact on energy usage	Potential impact on energy efficiency	Potential impact on safety
Transient events				
Voltage dips	x	x		
Voltage swells	x			
Voltage interruptions		x		
Voltage transients	x	x		x
Steady state events				
Voltage deviation	x		x	
Frequency deviation		x		
Voltage harmonics and *THD*	x		x	x Third harmonic and multiples
Voltage unbalance	x			
Voltage flicker		x		
Rapid voltage change		x		
Current harmonics and *THD*	x		x	
Power related events				
Power factor	x		x	

5.12 Synthesis of events impact on energy usage

See Table 8.

Table 8 – Overview of events and impact on usages

Event	Usages without mitigation				
	Motors	Lighting	Appliances	HVAC	Transformer
Transient events					
Voltage dips	x	x			
Voltage swells	x				
Voltage interruptions	x	x	x	x	x
Voltage transients	x	x	x		
Steady state events					
Voltage deviation	x				
Frequency deviation	x				
Voltage harmonics and *THD*	x				x
Voltage unbalance	x				
Voltage flicker		x			
Rapid voltage change	x	x			
Current harmonics and *THD*	x				
Power related events					
Power factor					

Annex A
(informative)

Example of the scope of a measurement plan: organization, sites, zones, energy uses

Figure A.1 below illustrates the relations that determine the links between the notions of organization, site, zone and energy use. To give an example, the area delineated by the dashed line represents the "scope of a DSPQ plan" specific to Plant 1.

When defining the scope of the measurement plan, it is possible – within a given zone – to integrate energy uses considered significant and to exclude others. The example of "zone 3" (only 3.1 is taken into account) illustrates this point.

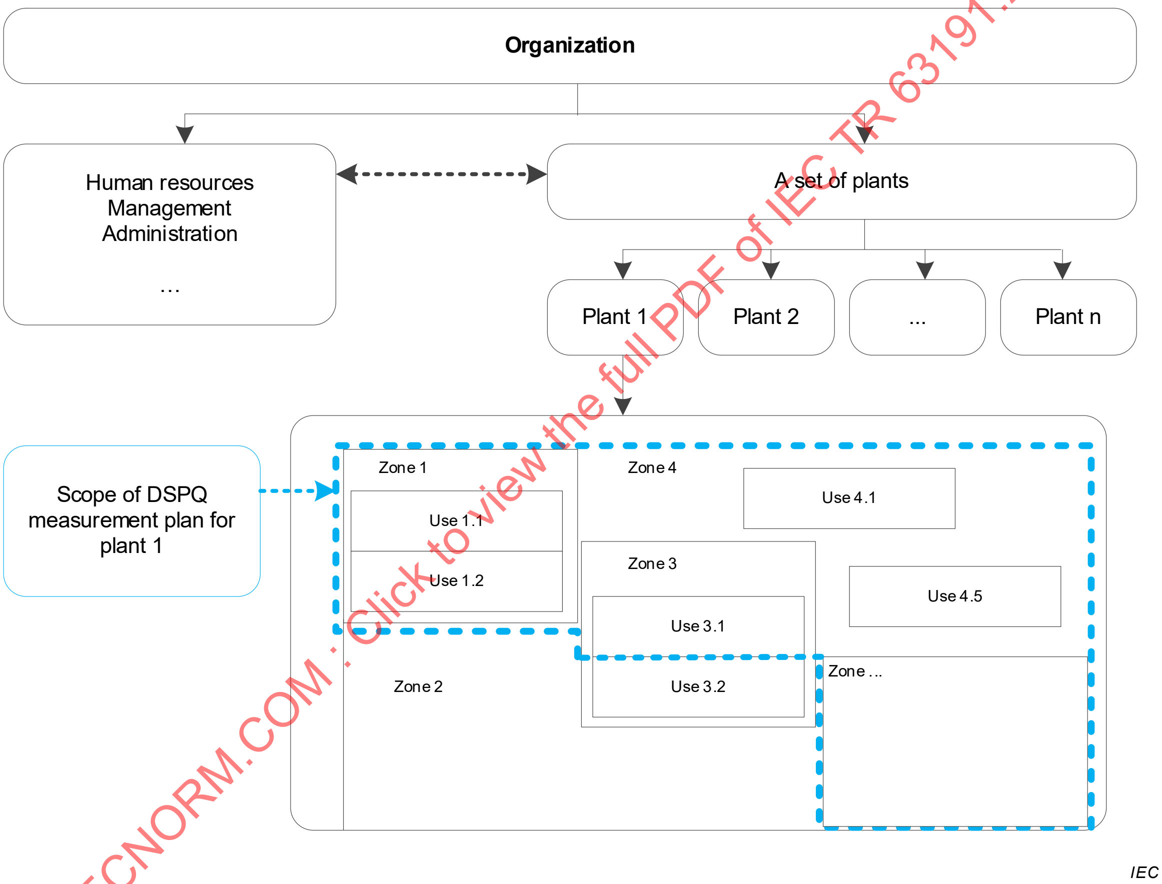


Figure A.1 – Example of the scope of a measurement plan

Annex B
(informative)

State of the art related to disturbance levels on the demand side PQ

B.1 General

Annex B defines the state of the art related to the levels of disturbances on the demand side, and defines three levels of disturbances according to the definitions specified in IEC 61000-2-4.

- Low level of disturbances: This level applies to protected supplies and has compatibility levels lower than those on public networks. It relates to the use of equipment very sensitive to disturbances in the power supply, for instance electrical instrumentation in laboratories, some automation and protection equipment, some computers.
- Medium level of disturbances: This level applies generally to PCCs and to IPCs in the environments of industrial and other non-public power supplies. The compatibility levels of this level are generally identical to those of public networks. Therefore, components designed for supply from public networks may be used in this level of industrial environment.
- High level of disturbances: This level applies only to IPCs in industrial environments. It has higher compatibility levels than those of medium level for some disturbance phenomena. For instance, this level should be considered when any of the following conditions are met:
  – a major part of the load is fed through converters;
  – welding machines are present;
  – large motors are frequently started;
  – loads vary rapidly.

NOTE These disturbance levels relate to class 1, 2 and 3 of IEC 61000-2-4. The electromagnetic environment classes defined in IEC 61000-2-4 relate to a limited set of PQ disturbances, while this document considers additional PQ disturbances.

The levels can be used for an individual circuit or for a mesh or for an installation, according to the classification given in Table B.1, Table B.2, Table B.3 and Table B.4.

B.2 Transients and short-term events

Table B.1 – Classification of transients and short-term events

Events		Low disturbance	Medium disturbance	High disturbance
Voltage dips, interruptions	Limits	CBEMA/ITIC requirements	0 % during 1 cycle max. 70 % during 25/30 cycles max.	0 % during 1 cycle max. 40 % during 10/12 cycles max. 70 % during 25/30 cycles max. 80 % during 250/300 cycles max.
	References	CBEMA/ITIC	IEC 61000-4-34: class 2 (supposed to cope with boxes A1, B1, A2 and B2 of EN 50160)	IEC 61000-4-34: class 3 (supposed to cope with boxes A1, B1, C1, A2, B2, A3 and A4 of EN 50160)
Voltage swells	Limits	< 110 % for 25 / 30 cycles	< 120 % for 25 / 30 cycles	> 120 % for 25 / 30 cycles
	References	Working Group proposal, within the safe area of CBEMA/ITIC curve	Working Group proposal, on the limit of the safe area of CBEMA/ITIC curve	Working Group proposal, outside the safe area of CBEMA/ITIC curve
Voltage transients	Limits	CBEMA/ITIC requirements	< 500 % of U_n	< 1 000 % of U_n
	References	CBEMA/ITIC	IEC TR 61000-2-14 and IEC 60664-1(cat I). More information for LV systems can be found in IEC TR 62066	IEC TR 61000-2-14 and IEC 60664-1 (cat II). More information for LV systems can be found in IEC TR 62066

CBEMA: Computer Business Equipment Manufacturers Association

ITIC: Information Technology Industry Council

B.3 Continuous voltage phenomena

Table B.2 – Classification of continuous voltage phenomena

Events		Low disturbance	Medium disturbance	High disturbance
Voltage deviation	Limits	$\Delta U/U_N$ < ±8 %	$\Delta U/U_N$ < ±10 %	$\Delta U/U_N$ < +10 % to −15 %
	References	IEC 61000-2-4:2002, class 1	IEC 61000-2-4:2002, class 2	IEC 61000-2-4:2002, class 3
Voltage unbalance	Limits	U_{neg}/U_{pos} < 2 %	U_{neg}/U_{pos} < 2 %	U_{neg}/U_{pos} < 3 %
	References	IEC 61000-2-4:2002, class 1	IEC 61000-2-4:2002, class 2	IEC 61000-2-4:2002, class 3
Frequency deviation	Limits	Δf < ±1 Hz	Δf < ±1 Hz	Δf < ±1 Hz
	References	IEC 61000-2-4:2002, class 1	IEC 61000-2-4:2002, class 2	IEC 61000-2-4:2002, class 3
Voltage flicker (flicker is mainly related to human perception)	Limits	P_{st} < 0,7 P_{lt} < 0,6	P_{st} < 1 P_{lt} < 0,8	P_{st} > 1 P_{lt} > 0,8
	References	Working Group proposal, based on typical power quality measurement graphs.	IEC 61000-2-2 compatibility levels and EN 50160	IEC 61000-2-2 compatibility levels and EN 50160
Rapid voltage change (RVC)	Limits	$\Delta U_{steady\ state}$ > 2 %, maximum 24 times per day ΔU_{max} > 5 %, maximum 24 times per day	$\Delta U_{steady\ state}$ > 3 %, maximum 24 times per day ΔU_{max} > 5 %, maximum 24 times per day	$\Delta U_{steady\ state}$ > 5 %, maximum 24 times per day ΔU_{max} > 6 %, maximum 24 times per day
	References	Working Group proposal, based on typical power quality measurement and IEC 61000-4-30	NOTE In Norway: EN 50160:2010/A1:2015	Working Group proposal, based on typical power quality measurement and IEC 61000-4-30
Voltage harmonics (U_h)	Limits (Odd order non multiple of 3)	Rank 5: 3 % Rank 7: 3 % Rank 11: 3 % Rank 13: 3 % Rank 17: 2 % Rank[17-49]: 2,27 × (17/h) − 0,27	Rank 5: 6 % Rank 7: 5 % Rank 11: 3,5 % Rank 13: 3 % Rank 17: 2 % Rank[17-49]: 2,27 × (17/h) − 0,27	Rank 5: 8 % Rank 7: 7 % Rank 11: 5 % Rank 13: 4,5 % Rank 17: 4 % Rank[17-49]: 4,5 × (17/h) − 0,5

Events		Low disturbance	Medium disturbance	High disturbance
	Limits (Odd order multiple of 3)	Rank 3: 3 % Rank 9: 1, 5% Rank 15: 0,3 % Rank 21:0,2 % Rank[21-45]: 0,2 %	Rank 3: 5 % Rank 9: 1,5 % Rank 15: 0,5 % Rank 21:0,4 % Rank[21-45]: 0,3 %	Rank 3: 6 % Rank 9: 2,5 % Rank 15: 2 % Rank 21:1,75 % Rank[21-45]: 1 %
	Limits (Even order)	Rank 2: 2 % Rank 4: 1 % Rank 6: 0,5 % Rank 8: 0,5 % Rank 10: 0,5 % Rank[10-50]: 0,25 × (10/h) + 0,25	Rank 2: 2 % Rank 4: 1 % Rank 6: 0,5 % Rank 8: 0,5 % Rank 10: 0,5 % Rank[10-50]: 0,25 × (10/h) + 0,25	Rank 2: 3 % Rank 4: 1,5 % Rank 6: 1 % Rank 8: 1 % Rank 10: 1 % Rank[10-50]: 1 %
	References	IEC 61000-2-4:2002, class 1	IEC 61000-2-4:2002, class 2	IEC 61000-2-4:2002, class 3
Voltage THD (THD_u)	Limits	THD_u < 5 %	THD_u < 8 %	THD_u < 10 %
	References	IEC 61000-2-4:2002, class 1	IEC 61000-2-4:2002, class 2	IEC 61000-2-4:2002, class 3

NOTE 1 Some experts report that the level of voltage inter-harmonics is supposed to be 100 times less important than the level of voltage harmonics.

NOTE 2 The flicker limitation also limits certain inter-harmonics.

B.4 Continuous current phenomena

Table B.3 – Classification of continuous current phenomena

Events		Low disturbance	Medium disturbance	High disturbance
Current *THD* (THD_i)	Limits	THD_i < 5 %	THD_i < 8 %	THD_i < 10 %
	References	Working Group proposal	Working Group proposal	Working Group proposal

NOTE 1 The *THD* is the ratio of the harmonic RMS value divided by the fundamental RMS, while the *TDD* is the ratio of the harmonic RMS divided by the full load (maximum demand). The *TDD* gives a better indication of the impact of the harmonics when the fundamental current is low. *TDD* and *THD* can be considered together.

NOTE 2 The measure of the harmonic power flow may provide an indication of the direction of the harmonic flow (i.e. consumer or generator of harmonics). A positive power flow means that the load consumes harmonics present in the system while a negative power flow indicates that the load is nonlinear and acts as a source of harmonic.

NOTE 3 The harmonic current can also be measured in the neutral conductors as harmonic multiples of three are in phase in the neutral.

B.5 Power-related events

Table B.4 – Classification of power-related events

Events		Low disturbance	Medium disturbance	High disturbance
Power factor	Limits	*PF* > 0,95	*PF* > 0,90	*PF* > 0,85
	References	IEC 60364-8-1:2015; EEPL4	IEC 60364-8-1:2015; EEPL2	IEC 60364-8-1:2015; EEPL1

Annex C
(informative)

State of the art about relationship between devices and electrical phenomena

Table C.1 summarizes the state of the art in this field, devices being either impacted, source or mitigation devices.

Table C.1 – Relationship between current-using equipment and electrical phenomena

Electrical phenomena		Current using equipment										
		Motors	Variable speed drives (VSD)	Transformers	Capacitors	Conventional generators (GenSet)	Uninterrupted Power Supply	Lightning	Office devices (computers, printers, TV, etc.) (SMPS)	Cabling	Programmable logic controllers (PLC)	Inverted based generators (PV, storage)
Transients and short-term events	Voltage dips	I,S	I,M				M	I	I		I	
	Voltage interruptions						M		I		I	
	Voltage swells	I					M	I	I		I	
	Voltage transients	I	I		S		M		I		I	
Long term voltage-based phenomena	Voltage deviation	I							I			S
	Voltage unbalance	I										
	Frequency deviation	I										
	Voltage flicker							I	S			
	Rapid voltage change (*RVC*)											
	Voltage harmonics (U_h)	I,S	S	S,I,M	S,I	I	S	S	S	I		S
	Voltage *THD* (THD_u)											
	Voltage inter-harmonics	I,S	S	S,I,M	S,I	I	S	S	S	I		S
Long term current-based phenomena	Current *THD* (THD_i) or *TDD*											
Power-related events	Power factor	S	M	S,I	M	I		S		I		
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance												

Table C.2 to Table C.12 provide additional details.

Table C.2 – Motors

Disturbance	I / S / M	Explanation
Voltage dips	I	Voltage dips can create transient overcurrents that damage the motor, or can cause motor stalling.
	S	Starting of large electric motors either individually or in groups can cause voltage dips in the local or adjacent areas.
	M	
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	Voltage transients stress the insulation on the motor's winding causing it to degrade over time or sometimes catastrophically fail.
	S	---
	M	---
Voltage deviation	I	An overvoltage at the motor's terminals greater than 10 % can substantially increase the core losses of the motor resulting in overheating. Low voltage at the terminals of a fully loaded motor also results in additional heating due to increased current flow.
	S	---
	M	
Voltage unbalance	I	Voltage unbalance is a major cause of motor failures. It generates high current unbalance, which causes additional losses and a temperature rise in the motor.
	S	---
	M	---
Frequency deviation	I	Significant frequency drift will result in additional heating of the windings. Frequency changes have an impact on motor efficiency and speed.
	S	Induction motors require reactive energy to create magnetic field, resulting in a poor power factor.
	M	---
Voltage flicker	I	---
	S	---
	M	
Rapid voltage change (*RVC*)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	---
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.3 – Variable speed drives

Disturbance	I / S / M	Explanation
Voltage dips	I	Variable speed drives are sensitive to voltage dips, which may cause their nuisance tripping.
	S	---
	M	Variable speed drives reduce inrush currents during motor starting and thus, reduce the depth or even eliminate the resulting voltage dips.
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	Voltage transients put stress on the drive's diodes and can cause them to prematurely fail.
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	---
	S	---
	M	Variable speed drives usually improve power factor upstream to the drives.
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.4 – Transformers

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	---
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	Poor power factor may lead to overloading, overheating and additional losses in transformers.
	S	Transformers require reactive energy and thus decrease power factor.
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.5 – Capacitors

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	The switching of capacitor banks causes voltage transients.
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (*RVC*)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	---
	S	---
	M	Capacitors are used for the power factor correction
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.6 – Conventional generators (Genset)

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	---
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	A leading power factor may lead to oversizing/overload of the generators set.
	S	---
	M	---

Table C.7 – Uninterrupted Power Supply (UPS)

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	---
	M	UPS protects downstream equipment from disturbances such as voltage dips, surges, transients, momentary disruptions, and complete outages.
Voltage interruptions	I	---
	S	---
	M	UPS protects downstream equipment from disturbances such as voltage dips, surges, transients, momentary disruptions, and complete outages.
Voltage swells	I	---
	S	---
	M	UPS protects downstream equipment from disturbances such as voltage dips, surges, transients, momentary disruptions, and complete outages.
Voltage transients	I	---
	S	---
	M	UPS protects downstream equipment from disturbances such as voltage dips, surges, transients, momentary disruptions, and complete outages.
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (*RVC*)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	Old generation UPS generate harmonics.
	M	---
Power factor	I	---
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.8 – Lighting

Disturbance	I / S / M	Explanation
Voltage dips	I	Voltage dips and swells create visual discomfort
	S	---
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	Voltage dips and swells create visual discomfort.
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	Voltage variations affect the lighting quality (flickering).
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	Some lighting systems generate harmonics (e.g. compact fluorescent lights).
	M	---
Power factor	I	---
	S	Fluorescent and discharge lamps are characterized by low power factor.
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.9 – Office equipment

Disturbance	I / S / M	Explanation
Voltage dips	I	Sensitive to all voltage variations (see CBEMA or equivalent).
	S	---
	M	---
Voltage interruptions	I	Sensitive to all voltage variations (see CBEMA or equivalent.)
	S	---
	M	---
Voltage swells	I	Sensitive to all voltage variations (see CBEMA or equivalent).
	S	---
	M	---
Voltage transients	I	Voltage transients create semiconductor stress and premature failure.
	S	---
	M	---
Voltage deviation	I	SMPS may be destroyed when supplied outside their specified voltage range.
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	SMPS can be a source of harmonics.
	M	---
Power factor	I	---
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.10 – Cabling

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	---
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	Harmonics generate heating in the cables. High harmonic levels may require oversizing of the neutral conductor.
	S	---
	M	---
Power factor	I	Poor power factor increases losses in the cables. It may lead to oversizing of the cables.
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.11 – Programmable logic controllers (PLCs)

Disturbance	I / S / M	Explanation
Voltage dips	I	Sensitive to all voltage variations (see CBEMA or equivalent).
	S	---
	M	---
Voltage interruptions	I	Sensitive to all voltage variations (see CBEMA or equivalent).
	S	---
	M	---
Voltage swells	I	Sensitive to all voltage variations (see CBEMA or equivalent). PLCs have been shown to shut down for voltage dips.
	S	---
	M	---
Voltage transients	I	Sensitive to all voltage variations (see CBEMA or equivalent).
	S	---
	M	---
Voltage deviation	I	---
	S	---
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	---
	M	---
Power factor	I	---
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table C.12 – Inverted based generators (PV, storage)

Disturbance	I / S / M	Explanation
Voltage dips	I	---
	S	---
	M	---
Voltage interruptions	I	---
	S	---
	M	---
Voltage swells	I	---
	S	---
	M	---
Voltage transients	I	---
	S	---
	M	---
Voltage deviation	I	---
	S	Rise voltage levels when operating in LV networks.
	M	---
Voltage unbalance	I	---
	S	---
	M	---
Frequency deviation	I	---
	S	---
	M	---
Voltage flicker	I	---
	S	---
	M	---
Rapid voltage change (RVC)	I	---
	S	---
	M	---
Voltage harmonics, voltage inter-harmonics, current harmonics	I	---
	S	Source of harmonics and supra-harmonics.
	M	---
Power factor	I	---
	S	---
	M	---
I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Annex D
(informative)

General statements about demand side power quality

The quality of electrical energy has become a major concern in recent years particularly for the following reasons:

- spread of equipment disturbing and sensitive to the electrical energy quality (power electronics, frequency converters, IT equipment or process control units);
- need to increase the energy availability for better reliability, economic competitiveness, quality of services and data security;
- vulnerability of the electrical distribution networks due to the electricity market deregulation, decentralized power sources (photo-voltaic, wind turbines, combined heat and power plant, etc.), new loads appearing (e.g. electric vehicles) and energy storage integration;
- demand for sustainable development and energy efficiency, which in their turn depend on the quality of the electrical energy;
- growing number of extra-charges, penalties or compensations for injected or delivered electrical energy disturbances.

These reasons lead to requirements for better monitoring of electrical installations, with more measurement points and more measured energy quality indicators.

A demand side electric network may be subject to disturbances carried by the distribution network. It can also generate internal disturbances that may impact his own electrical installation, the electrical installation of neighbours and the public distribution network.

Technical publications consider that the origin of electrical disturbances on the demand side is typically split:

- Most electrical disturbances are generated within the electrical installation (power electronic equipment, motors starting, equipment switching on and off, defective devices, improper wiring, etc.).
- The rest of the electrical disturbances are coming from the supply side or from neighbour electrical installations.

This estimation can of course vary in function of the geography and the demand side electrical installation.

But as most disturbances in grids are coming from the demand side, it is important for technical managers to manage them in order to avoid:

- supplier penalties,
- unwanted tripping of protections, leading to electrical blackouts,
- deterioration of materials, reduction of lifetime,
- production interruption or IT dysfunction,
- troubleshooting with the smart grid, e.g. renewable energy.
- incidences on energy efficiency.

It is also important for utilities to avoid having their grid polluted by disturbances coming from customers on the demand side.

Disturbances in the network are creating power quality issues. The term “power quality” usually refers to the power quality at the point of common coupling (PCC), but it can also apply to the whole demand side.

Annex E
(informative)

Consequence of grid evolution

The grid has evolved from being a centralized and unidirectional power system structure (Figure E.1) to a distributed and bidirectional power system structure – power exchange system (Figure E.2).

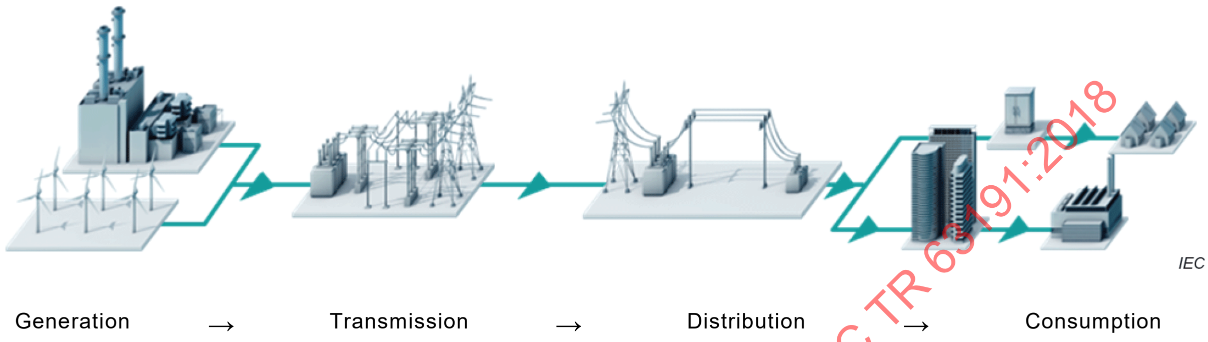


Figure E.1 – The old centralized grid

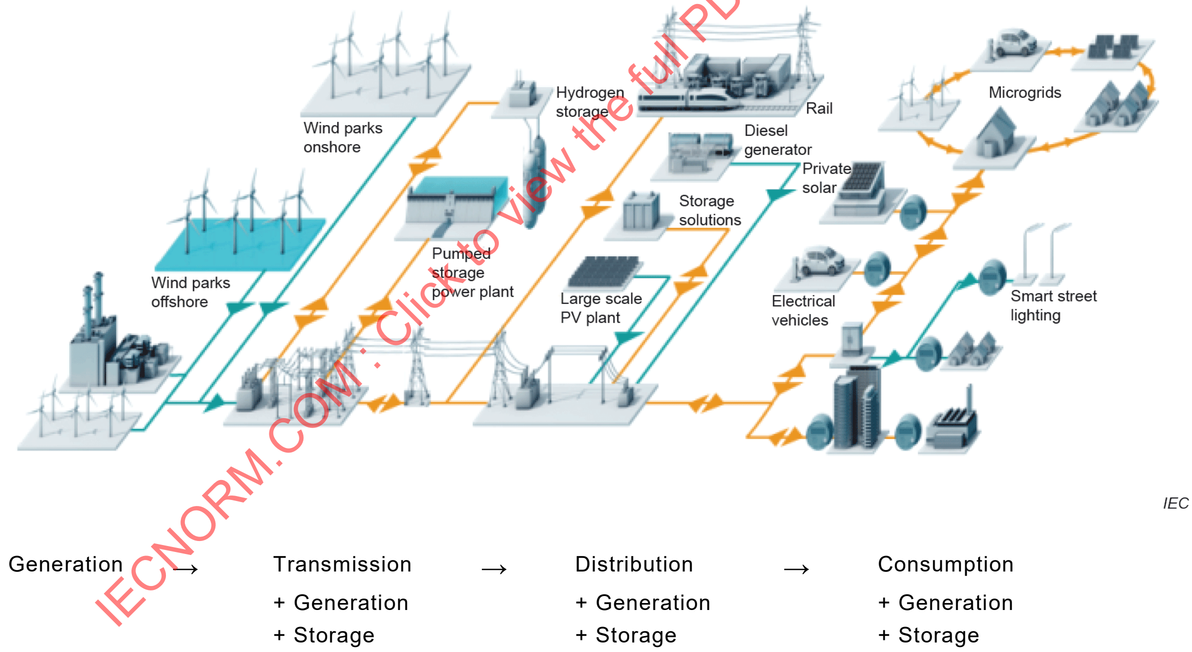


Figure E.2 – The new decentralized grid

This evolution has created a series of problems including power quality issues such as:

- fluctuating power infeed;
- change in energy flow direction;
- where are the sources of disturbances measured at the PCC?
- decrease in short-circuit capacity of the power system.

The consequences are:

1) unpredictable fluctuating power infeed from renewable sources (DG):

– at the upper voltage levels (wind parks),
– at low voltage level (PV installations),

leading to voltage deviations, flicker (see Figure E.3).

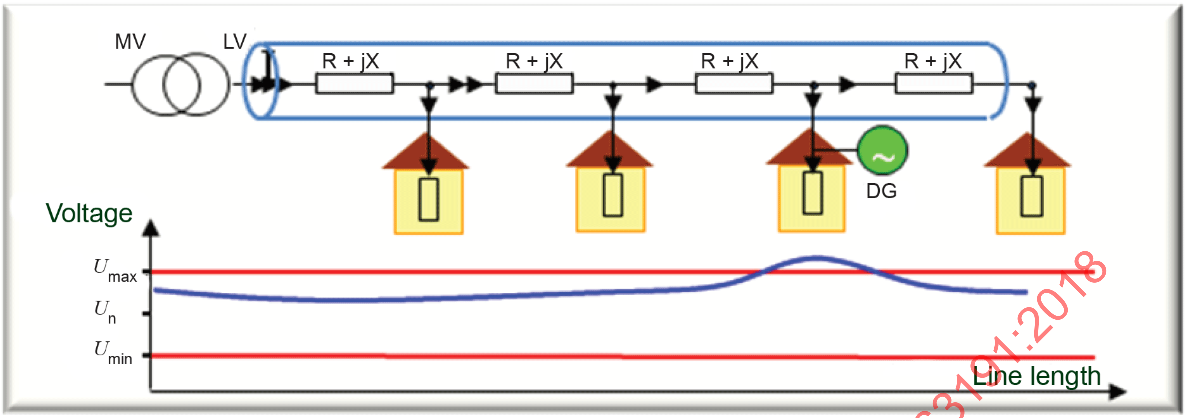


Figure E.3 – Example of consequences of a decentralized grid

2) change in the energy flow direction, including energy transmission to higher voltage levels leading to harmonics infeed at all voltage levels, caused by:
   – inverters (PV, fuel cells and storage systems),
   – frequency converters (gas turbines, wind power),
   – the addition of non-linear loads to the power system.

Annex F
(informative)

Non-exhaustive list of relevant standards

Table F.1 provides existing requirements on levels, Table F.2 provides compatibility levels and Table F.3 provides existing product standards.

Table F.1 – Existing requirements about PQ (non-exhaustive list)

Requirements at PCC	Requirements on the demand side
For public networks delivery at PCC EN 50160 (IEC TS 62749) IEEE 519 ER G5/4-1 For private installation connected to PCC IEC TR 61000-3-6 (connection to MV and HV power systems) IEC TR 61000-3-14 (connection to LV power systems) Technical rules for the assessment of network disturbances: D-A-CH-CZ	Installation IEC 60364-8-1, Low-voltage electrical installations – Part 8-1: Energy efficiency SEMI F47 Specification for Semiconductor Processing Equipment Voltage Sag Immunity CBEMA/ITIC – the power acceptability curve for computer business equipment Power Vaccine Equipment IEC 61000-3-2, Electromagnetic compatibility (EMC) – Part 3-2: Limits for harmonic current emissions (equipment input current ≤16 A per phase) IEC 61000-3-12, Electromagnetic compatibility (EMC) – Part 3-12: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase IEC 61000-4-11, Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests IEC 61000-4-34, Electromagnetic compatibility (EMC) – Part 4-34: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase Power drive systems IEC 61800-3, Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods Power converters IEEE 519-1992 – IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems Rotating machines IEC 60034-1, Rotating electrical machines – Part 1: Rating and performance IEC 60034-15, Rotating electrical machines – Part 15: Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines NEMA MG-1 Motors and Generators Lifts EN 12015 emission limits in relation to electromagnetic disturbances and test conditions for lifts, escalators and moving walks

Table F.2 – Compatibility levels

Requirements at PCC	Requirements on the demand side
IEC 61000-2-2 Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems	IEC 61000-2-4, Electromagnetic compatibility (EMC) – Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances

Table F.3 – Existing requirements about disturbance measurement methods and instruments (non-exhaustive list)

Requirements at PCC	Requirements on the demand side
Power Quality Instruments (PQI-A class A and PQI-S class S) [a]: IEC 62586-1 and IEC 62586-2 Measuring methods: IEC 61000-4-30 IEEE Std 1159: IEEE recommended practice for Monitoring Electric Power Quality	Power Meters: IEC 61557-12
[a] These devices can be used on the demand side as well.	

Annex G
(informative)

Definitions of electrical parameters

G.1 General

Annex G provides common definitions and methods for measuring electrical quantities as given in IEC 61557-12.

Further guidance can be found in IEC 61557-12.

G.2 Definitions in the presence of a neutral

Table G.1 lists symbols used in Annex G. Table G.2 specifies how to calculate the parameters.

Table G.1 – Definition of symbols

Symbol	Definition
N	Number of samples in one fundamental period
M	Number of samples used for measurement (length of measurement window)
Δt	Duration of the measurement window in seconds
k	Index of a sample within the measurement window ($0 \leq k \leq M - 1$)
p	Index of a phase (p = 1, 2 or 3; or p = a, b, c; or p = r, s, t; or p = R, Y, B)
g	Index of a phase (g = 1, 2 or 3; or g = a, b, c; or g = r, s, t; or g = R, Y, B)
N_{ph}	Number of phases excluding neutral (generally 1 or 3)
i_{pk}	Phase p current sample number k
i_{Nk}	Measured neutral current sample number k
v_{pk}	Phase p to neutral voltage sample number k
v_{gk}	Phase g to neutral voltage sample number k
u_{pgk}	Phase p to phase g voltage sample number k: $u_{pgk} = v_{pk} - v_{gk}$
φ_p	Phase angle between the fundamental current and the fundamental voltage for phase p
h_{max}	Maximum harmonic rank used for harmonic measurements
$I_{i,p}$	Harmonic current of rank i in phase p (RMS value)
$I_{N,i}$	Harmonic current of rank i in the neutral (RMS value)
$V_{i,p}$	Harmonic phase p to neutral voltage of rank i (RMS value)
$\varphi_{i,p}$	Phase angle between harmonic current and harmonic voltage at rank i on phase p
$U_{i,pg}$	Harmonic phase p to phase g voltage of rank i (RMS value)
$I_{1,p,maxdem}$	Maximum 15 min or 30 min demand value of fundamental current for phase p

Symbol	Definition
X	Generic symbol of an electrical quantity within a formula, to be replaced by I, I_p or I_N for current, by V or V_p for phase to neutral voltage, or by U or U_{pg} for phase to phase voltage
X_{neg}	Negative-sequence component of electrical quantity X considering its decomposition into symmetrical components
X_{pos}	Positive-sequence component of electrical quantity X considering its decomposition into symmetrical components
X_{zero}	Zero-sequence component of electrical quantity X considering its decomposition into symmetrical components
X_{1cy} ($X_{1/2cy}$)	RMS value of electrical quantity X (current or voltage) measured over 1(1/2) fundamental cycle and refreshed for each cycle
X_{ref}	Reference RMS value used to detect and characterize dips and swells, may be a fixed value or a time-varying value
X_{res}	Lowest X_{1cy} or $X_{1/2cy}$ value measured during a dip event
X_{swell}	Highest X_{1cy} value measured during a swell event

The calculation methods in Table G.2 are reference algorithms for computing electrical quantities in the general case.

Depending on the characteristics of a PMD, different implementations are possible. Manufacturers of PMDs not using these formulas should document the calculation methods used in the product.

Table G.2 – Calculation definitions for electrical parameters

Item	Symbol and definition
RMS values	
RMS current in phase p	$I_p = \sqrt{\dfrac{\sum_{k=0}^{M-1} ip_k^2}{M}}$
Phase p to neutral RMS voltage	$Vp = \sqrt{\dfrac{\sum_{k=0}^{M-1} vp_k^2}{M}}$
Phase p to phase g RMS voltage	$Upg = \sqrt{\dfrac{\sum_{k=0}^{M-1} (upg_k)^2}{M}}$
Total (or average) RMS current or voltage	$X = \dfrac{\sum_{p=1}^{N_{ph}} X_p}{N_{ph}}$
Calculated RMS neutral current	$I_N = \sqrt{\dfrac{\sum_{k=0}^{M-1} (i1_k + i2_k + i3_k)^2}{M}}$

Item	Symbol and definition
Phase powers	
Active power for phase p	$P_{\mathrm{p}} = \frac{1}{M} \cdot \sum_{k=0}^{M-1} (v\mathrm{p}_k \times i\mathrm{p}_k)$
Apparent power for phase p	$S_{\mathrm{p}} = V_{\mathrm{p}} \times I_{\mathrm{p}}$
Reactive power for phase p, power triangle formula (also known as Fryze's definition) [a]	$Q\mathrm{p} = Q\mathrm{p}_{\mathrm{trian}} = \mathrm{Sign}Q(\varphi_{\mathrm{p}}) \times \sqrt{S\mathrm{p}^2 - P\mathrm{p}^2}$ with $\mathrm{Sign}Q(\varphi_{\mathrm{p}}) = +1 \text{ if } \varphi_{\mathrm{p}} \in [0° - 180°]$ $\mathrm{Sign}Q(\varphi_{\mathrm{p}}) = -1 \text{ if } \varphi_{\mathrm{p}} \in [180° - 360°]$ NOTE This quantity is sometimes referred to as the non-active power.
Reactive power for phase p, quadrature phase shift formula [a,c]	$Q\mathrm{p} = Q\mathrm{p}_{\mathrm{quad}} = \frac{1}{M} \cdot \sum_{k=0}^{M-1} (v\mathrm{p}_{k-N/4} \times i\mathrm{p}_k)$
Reactive power for phase p, Budeanu's harmonic definition [a,c]	$Q\mathrm{p} = Q\mathrm{p}_{\mathrm{harm}} = \sum_{i=1}^{h_{\mathrm{max}}} I_{i,p} \cdot V_{i,p} \cdot \sin(\varphi_{i,p})$
Distortion power	$D\mathrm{p} = \sqrt{S^2 - P^2 - Q^2}$
Phase energies	
Active energy for phase p	$E_{\mathrm{p}} = P_{\mathrm{p}} \cdot \Delta t$
Reactive energy for phase p	$E_{\mathrm{rp}} = Q_{\mathrm{p}} \cdot \Delta t$
Apparent energy for phase p	$E_{\mathrm{ap}} = S_{\mathrm{p}} \cdot \Delta t$
Total powers	
Total active power	$P = \sum_{p=1}^{N_{\mathrm{ph}}} P_{\mathrm{p}}$
Total reactive power (vector)	$Q\mathrm{V} = \sum_{p=1}^{N_{\mathrm{ph}}} Q_{\mathrm{p}}$
Total apparent power (vector)	$S\mathrm{V} = \sqrt{P^2 + Q\mathrm{V}^2}$
Total apparent power (arithmetic)	$S\mathrm{A} = \sum_{p=1}^{N_{\mathrm{ph}}} S_{\mathrm{p}}$
Total reactive power (arithmetic) [b]	$Q\mathrm{A} = \sqrt{S\mathrm{A}^2 - P^2}$
Power factors	
Power factor for phase p	$PF_{\mathrm{p}} = \frac{P_{\mathrm{p}}}{S_{\mathrm{p}}}$ NOTE The power factor is sometimes defined with an absolute value on the numerator.
Displacement power factor for phase p	$DPF_{\mathrm{p}} = \cos(\varphi_{\mathrm{p}})$

Item	Symbol and definition
Total power factor (vector)	$PF_V = \frac{P}{S_V}$
Total power factor (arithmetic)	$PF_A = \frac{P}{S_A}$
Fundamental powers	
Fundamental active power on phase p	$P_{1,p} = I_{1,p} \cdot V_{1,p} \cdot \cos(\varphi_p)$
Fundamental reactive power on phase p	$Q_{1,p} = I_{1,p} \cdot V_{1,p} \cdot \sin(\varphi_p)$
Fundamental apparent power on phase p	$S_{1,p} = I_{1,p} \cdot V_{1,p}$
Distortion indicators	
Harmonic distortion of electrical quantity X (I_p, V_p, or U_{pg}) – Phase quantity	$THDX_p = \frac{\sqrt{\sum_{i=2}^{h_{max}} X_{i,p}^2}}{X_{1,p}}$
Harmonic distortion referred to RMS of electrical quantity X (I_p, V_p, or U_{pg}) – Phase quantity	$THD\_RX_p = \frac{\sqrt{\sum_{i=2}^{h_{max}} X_{i,p}^2}}{X_p}$
Total harmonic distortion of electrical quantity X (I, V, or U)	$THDX = \frac{\sum_{p=1}^{N_{ph}} THDX_p}{N_{ph}}$
Total harmonic distortion referred to RMS of electrical quantity X (I, V, or U)	$THD\_RX = \frac{\sum_{p=1}^{N_{ph}} THD\_RX_p}{N_{ph}}$
Total distortion ratio of electrical quantity X (I, V, or U) – Phase quantity	$TDRX_p = \frac{\sqrt{X_p^2 - X_{1,p}^2}}{X_{1,p}}$ NOTE Unlike the THD, this distortion ratio contains the contribution of interharmonic components.
Total distortion ratio of electrical quantity X (I, V, or U)	$TDRX = \frac{\sum_{p=1}^{N_{ph}} TDRX_p}{N_{ph}}$
Distortion active power on phase p	$PD_p = P_p - P_{1,p}$
Total distortion active power	$PD = \sum_{p=1}^{N_{ph}} PD_p$
Total demand distortion (current) on phase p	$TDD_p = \frac{\sqrt{\sum_{i=2}^{h_{max}} I_{i,p}^2}}{I_{1,p,maxdem}}$