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TECHNICAL SPECIFICATION

colour inside

Demand-side power quality management

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DEMAND-SIDE POWER QUALITY MANAGEMENT

FOREWORD

IEC TS 63191 has been prepared by IEC technical committee 85: Measuring equipment for electrical and electromagnetic quantities. It is a Technical Specification.

This first edition cancels and replaces IEC TR 63191, published in 2018. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) a new informative Annex A describing a tool to report the ability to assess the power quality of an electrical installation.

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

Draft	Report on voting
85/893/DTS	85/902/RVDTS

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

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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- withdrawn,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.

IMPORTANT – The "colour inside" logo on the cover page of this document 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 can be significantly worse and can 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 inadequate 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. 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).

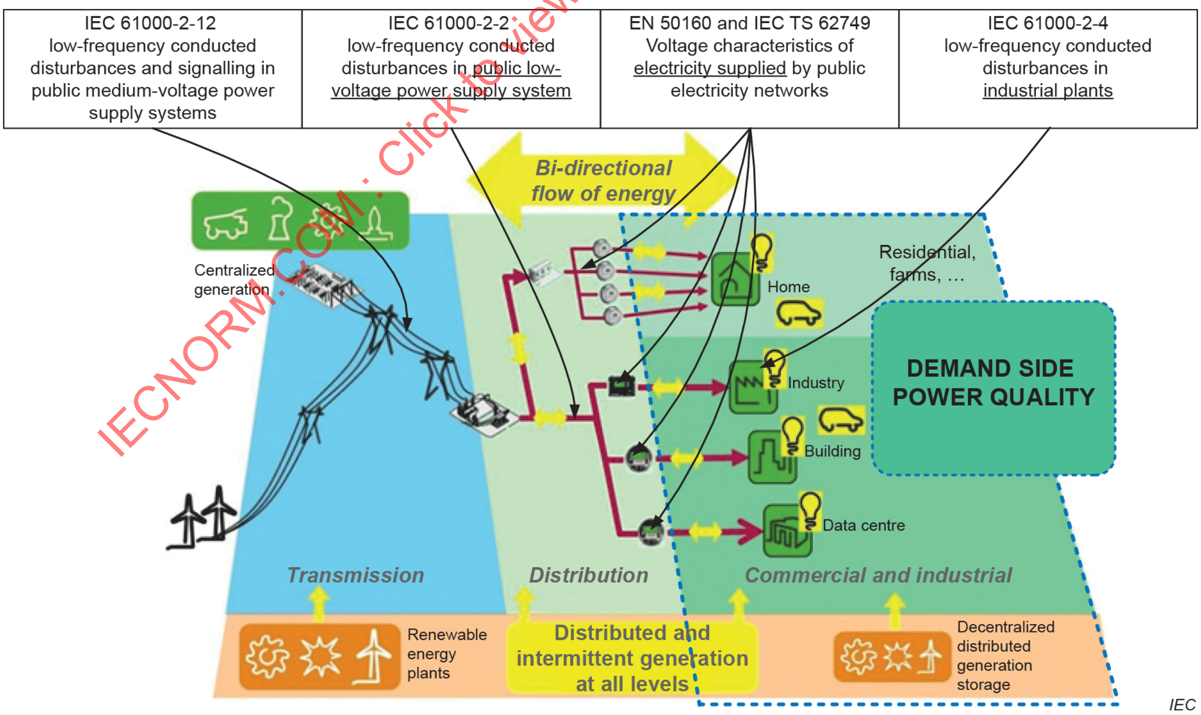


Figure 1 – Overview of electrical distribution system from supply side to demand side, with related standards

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

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

See Annex A for a tool to report the ability to assess the power quality.

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

See Annex F for a discussion about grid evolution.

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

See Annex H for definition of electrical parameters.

It is assumed that users of this document 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 address 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 refers to 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 phases:

- 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 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 can 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 can 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 can 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 – In the definition, "phase voltages" has been replaced with "line voltages (fundamental component)" and "consecutive phases" has been replaced with "consecutive line voltages". 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 can, 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 – In the definition, "or demand-side power quality" has been added.]

3.14
supraharmonics
disturbances in the range of 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 61557-12:2018, 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]

3.18
MCS
mains communicating system
electrical system using mains power lines to transmit information signals, either on the power supply system or within installations of network users

3.19
organization
person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

[SOURCE: ISO 50001:2018, 3.1.1]

3.20
facility manager
professional who ensures a company's services meet workers needs

Note 1 to entry: Facility managers inspect and repair electrical, plumbing or janitorial problems. In addition, they are responsible for collecting data and analysing it to adjust to current processes and plans.

3.21
zone
area (or surface) defining a part of an installation

[SOURCE: IEC 60364-8-1:2019, 3.1.1, modified – The note has been deleted.]

3.22
use
type of application for which electricity is used

4 Phases of a measurement plan

4.1 Six-phase measurement plan

Whereas Annex E provides general statements about demand-side power quality for an organization, 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).

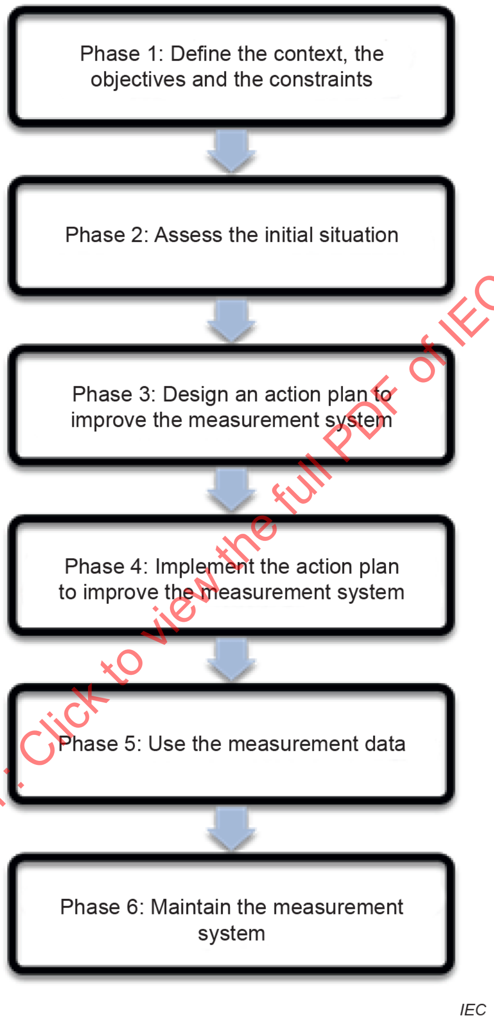


Figure 2 – Six-phase measurement plan

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 and 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 and Annex B.

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 shall 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:

- summary of its objectives and its constraints;
- indication of adoption of the organizational structure;
- implementation schedule for the DSPQ improvement plan;
- budget allocation for 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 1 In Europe, utilities deliver electrical energy according to the quality level defined in EN 50160.

  NOTE 2 In some countries, according to the regulator, DSOs send some PQ data annually to their MV customers.
- type of earthing system used (TT, TN, etc. according to IEC 60364-1:2005);
- local production of energy;
- disruptive neighbourhoods sites.

According to these factors, the organization shall 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 as created by the organization.

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

Measuring point	Location	Measured parameter	Reading method (manual or 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 need 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, portable 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 C provides the state-of-the-art related to disturbance levels on the DSPQ. The organization should use Annex C to define, on the relevant identified variables, the different levels of quality (low disturbance, medium disturbance or high disturbance).

According to these levels, Annex C 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 shall 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

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

Some equipment can be installed and commissioned by the installer or the manufacturer. In this case, the cost of installation shall 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, phase 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 C.

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 can be analysed by external experts.

4.6.4 Dissemination and protection of power quality data

This data shall 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 shall be verified according to the manufacturer's specifications.

4.7.4 Deliverables for phase 6

Maintenance planning for the measurement devices and maintenance report.

Device firmware and software can be updated.

The system shall 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 D.

See Table 2, Table 3 and Table 4.

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

Table 2 – Classification of PQ phenomena

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

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 or aging or both
	Production loss
	Waste of raw material
	Loss of data
	Increased losses in electrical equipment and distribution system
	Disturbance and interference to electronic 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 a stable interconnected utility grid.

However, it is possible to experience significant frequency deviations in the 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 can cause a motor to run faster or slower to match the frequency of the input power. This would cause the motor to run inefficiently or lead to overheating and motor attrition or both.

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 can lead to erratic operation, data loss and system crashes.

5.2.2.3 Effects on other equipment

Important frequency variations can 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. These voltage values are the most commonly used values 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.

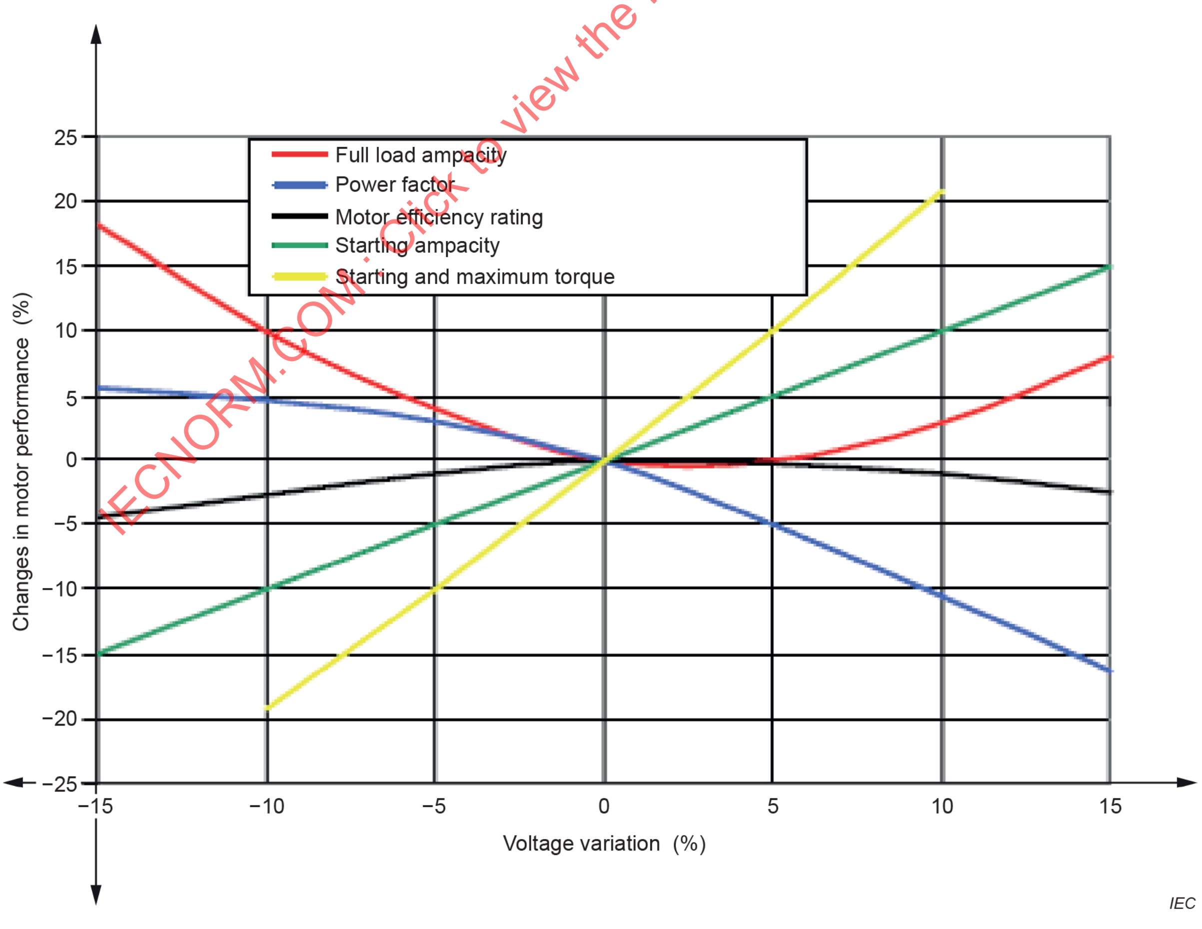


Figure 3 – Effects of voltage deviation on a motor

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 can 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 an incandescent light bulb will be decreased with overdeviation.

NOTE Incandescent light bulbs are becoming obsolete.

5.3.3 Possible mitigation measures

If equipment is installed that is sensitive to overdeviation or underdeviation or both, use a voltage stabilizer.

If supply voltage is permanently underdeviated, 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 a 2 h time period can 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 their 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 or synchronous machines or both 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 installation;
- switching of heavy loads or start-up of large motors;
- malfunction in voltage stabilization systems such as UPS, power conditioners, voltage regulators and 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 or voltage regulator;
- utility PQ improvement partnership;
- immune loads.

5.5.4 Key parameters to measure

Voltage events (voltage dips, interruptions and swells) are short-duration random events that are difficult to observe. Service calls are expensive; it can take a long time to measure and identify the problem with portable instruments. Only continuous measurements with the right instrument guarantee a reliable recording of these transient disturbances. Monitoring devices shall 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, respectively).

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

<table>
<tr><th>Residual voltage, U [%]</th><th colspan="15">Duration, t [ms]</th></tr>
<tr><td></td><td colspan="3">10 ≤ t ≤ 200</td><td colspan="3">200 < t ≤ 500</td><td colspan="3">500 < t ≤ 1 000</td><td colspan="3">1 000 < t ≤ 5 000</td><td colspan="3">5 000 < t ≤ 60 000</td></tr>
<tr><td>90 > U ≥ 80</td><td colspan="3">CELL A1</td><td colspan="3">CELL A2</td><td colspan="3">CELL A3</td><td colspan="3">CELL A4</td><td colspan="3">CELL A5</td></tr>
<tr><td>80 > U ≥ 70</td><td colspan="3">CELL B1</td><td colspan="3">CELL B2</td><td colspan="3">CELL B3</td><td colspan="3">CELL B4</td><td colspan="3">CELL B5</td></tr>
<tr><td>70 > U ≥ 40</td><td colspan="3">CELL C1</td><td colspan="3">CELL C2</td><td colspan="3">CELL C3</td><td colspan="3">CELL C4</td><td colspan="3">CELL C5</td></tr>
<tr><td>40 > U ≥ 5</td><td colspan="3">CELL D1</td><td colspan="3">CELL D2</td><td colspan="3">CELL D3</td><td colspan="3">CELL D4</td><td colspan="3">CELL D5</td></tr>
<tr><td>5 > U</td><td colspan="3">CELL X1</td><td colspan="3">CELL X2</td><td colspan="3">CELL X3</td><td colspan="3">CELL X4</td><td colspan="3">CELL X5</td></tr>
<tr><td>Swell voltage, U [%]</td><td colspan="15">Duration, t [ms]</td></tr>
<tr><td></td><td colspan="5">20 ≤ t ≤ 500</td><td colspan="5">500 < t ≤ 5 000</td><td colspan="5">5 000 < t ≤ 60 000</td></tr>
<tr><td>U ≥ 120</td><td colspan="5">CELL S1</td><td colspan="5">CELL S2</td><td colspan="5">CELL S3</td></tr>
<tr><td>120 > U ≥ 110</td><td colspan="5">CELL T1</td><td colspan="5">CELL T2</td><td colspan="5">CELL T3</td></tr>
</table>

Table 6 – Voltage event classification according to IEC TS 62749

Residual voltage, U [%]	**Duration,** t [ms]				
	10 ≤ 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 ITIC curve, which is also known as the ITI curve or CBEMA curve (see Figure 4).

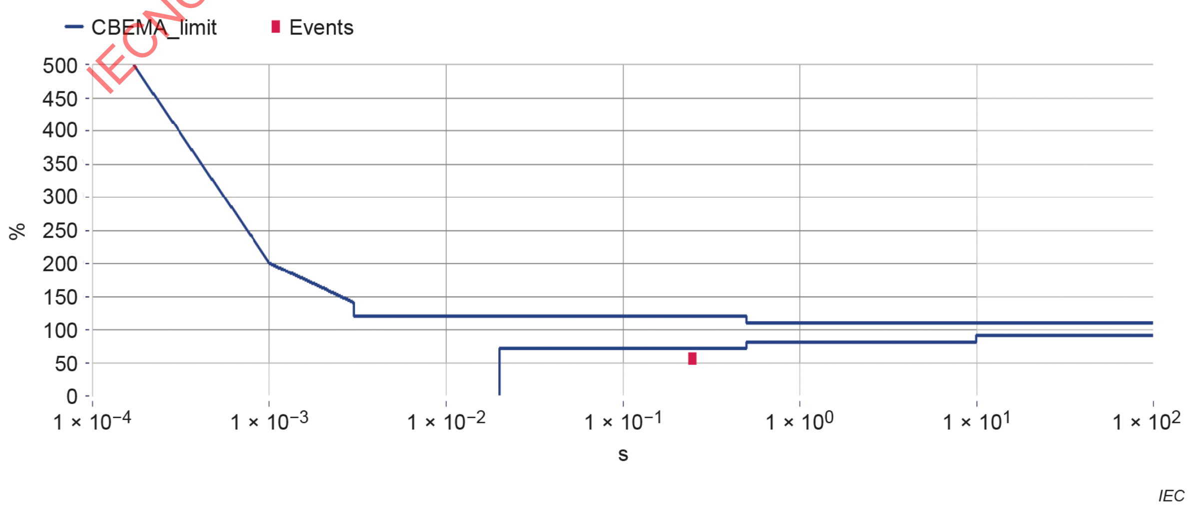


Figure 4 – Visualization of voltage events in modified ITI curve

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 a 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 (more accurately called a transition duration per IEC 60469:2013) 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.

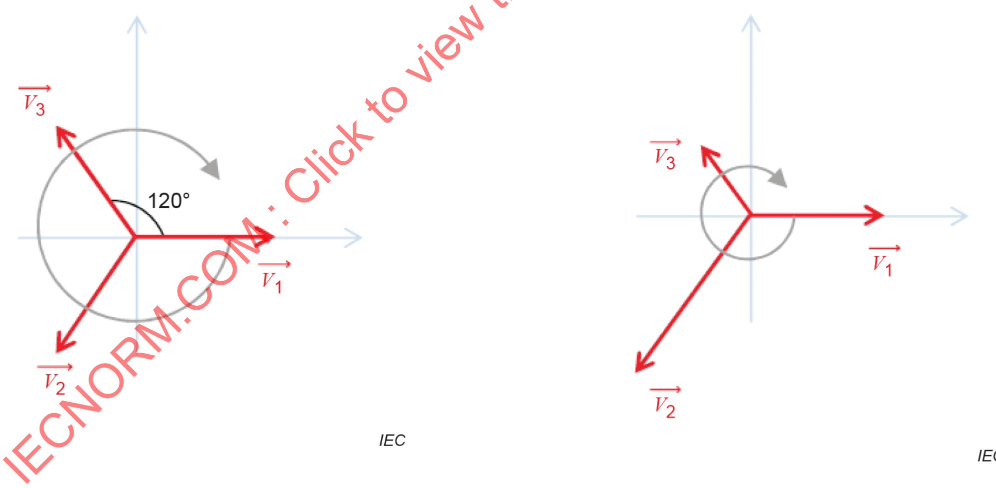
Measuring devices typically use one of two techniques to detect transient overvoltages. The first method, peak detection, can provide the user with information related to a transient overvoltage time of occurrence, magnitude, and duration. The peak detection method is less expensive, but it does not 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 analogue-to-digital converter although it is more expensive than a peak detector. 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 three-phase system

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

Figure 5 – Examples of balanced and 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 to a current unbalance greater 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 (according to IEC 61000-4-30:2015):

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

$$u_2 = \frac{U_2}{U_1} = \frac{\text{ns}}{\text{ps}}$$

where

ns is the negative sequence

ps is the positive sequence

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

$$u_0 = \frac{U_2}{U_1} = \frac{\text{zs}}{\text{ps}}$$

where

zs is the zero sequence

ps is the positive sequence

Second approach:

$$\text{vu} = \frac{\text{mdfm}\{V_{ab},V_{bc},V_{ca}\}}{\text{m}\{V_{ab},V_{bc},V_{ca}\}}$$

where

vu is the voltage unbalance

mdfm is the maximum deviation from mean of

m is the mean of

The voltage unbalance should not exceed 2 %.

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

5.8.1 Origins

A difference shall be made between the three kinds of harmonics:

Harmonics: A sinusoidal component of a periodic wave having a frequency that is an integer multiple of the fundamental frequency.

EXAMPLE 1 300 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 2 175 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 3 30 Hz is the sub-harmonic rank 0,6 of a 50 Hz signal.

In the following, the term harmonic can 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 frequency content as that of 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.

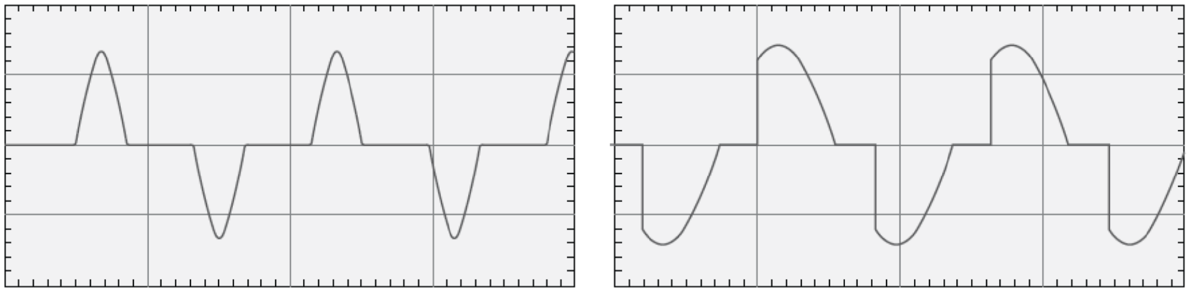


Figure 6 – Typical current waveforms for single-phase non-linear loads

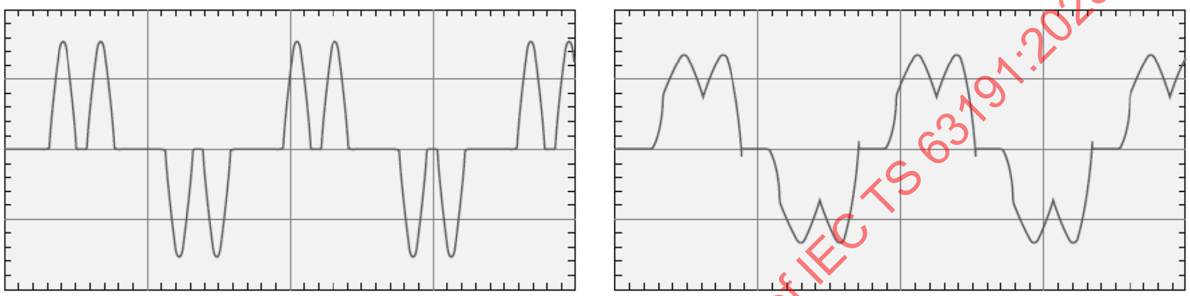


Figure 7 – Typical current waveforms for three-phase non-linear loads

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 can remain unnoticed, but it is possible that economical results are 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 to 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 lifetime 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

Total harmonic distortion (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 can 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 Origins

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

Limits to mains signalling voltage are given in EN 50065.

5.9.2 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 MCS.

5.9.3 Possible mitigation measures

Determine where the resonance occurs, or where the signal is attenuated, and identify the equipment causing the problem.

5.9.4 Key parameters to measure

MCS.

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 RVCs 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 or re-design or both 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} (U_{n} declared) as illustrated in Figure 8).

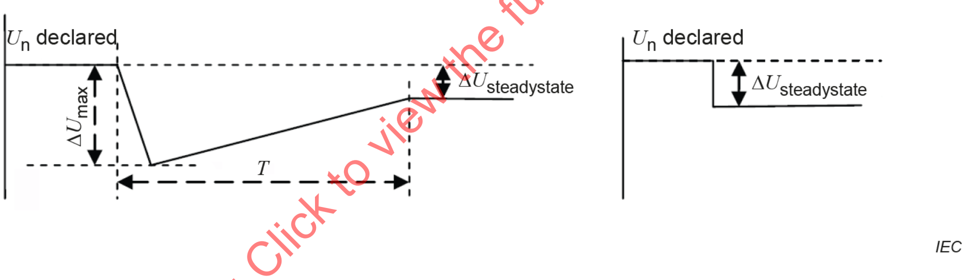


Figure 8 – RVC characterization

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 (informative), Deviation 3.17 for Norway only. Rapid voltage changes should be within limits at all supply terminals 100 % of the time as illustrated in Table 7.

Table 7 – Rapid voltage change limits

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

5.11 Synthesis of events and their impacts

See Table 8.

Table 8 – 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 and their impact on energy usage

See Table 9.

Table 9 – 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)

Tool to report the ability to assess the power quality of an electrical installation

A.1 General

Power quality events in the electrical network influence the efficiency of energy utilization for various processes, equipment and devices. Better power quality helps to improve the energy performance of an electrical installation.

Power quality instruments (PQI) are dedicated to measuring power quality parameters such as continuous voltage phenomena (voltage and frequency deviation, voltage harmonics and THD, current harmonics and THD, voltage unbalance, voltage flicker and rapid voltage change) and short-term events (voltage dips, swells, interruptions and transients).

NOTE 1 PQI-A and PQI-S are covered in IEC 62586-1.

Power metering and monitoring devices (PMD) are dedicated to measuring power monitoring parameters such as energy, power, PF and THD.

NOTE 2 PMD-I, PMD-II and PMD-III are covered in IEC 61557-12.

The objective of this Annex A is to provide a tool to report the ability to assess the power quality of an electrical installation. The tool is based on the relevant parameters influencing the power quality on demand side, in accordance with the principles described in the main clauses of this document. This tool applies to both new and existing installations, in premises used for purposes including industrial, commercial and infrastructure.

Engineering offices, consultants, and energy managers can use this tool.

The ability to assess the power quality of an electrical installation is the combination between the implementation of an optimal power quality monitoring system and a relevant power quality expertise.

A.2 Ability to assess the power quality of an electrical installation

The ability to assess the power quality of an electrical installation is rated into one of the following levels from the lower level to the higher level: DSPQ0, DSPQ1, DSPQ2 and DSPQ3, as illustrated in Figure A.1.

Figure A.1 – Ability levels to assess the power quality of an electrical installation

Recommended levels for different applications are given in Table A.22.

A.3 Determination of the ability to assess the power quality of an electrical installation

A.3.1 General

The ability to assess the power quality of the electrical installation is determined by adding together all the points obtained from the tables corresponding to each parameter given in A.3.2 to A.3.7.

Where a parameter is not covered, then 0 point is given for that parameter.

The total number of points is then compared with the number of points given in Table A.1 to determine the ability level to assess the power quality of the electrical installation.

Table A.1 – Electrical installation power quality ability levels

Electrical installation power quality ability level	Total number of points
Level DSPQ0	from 0 to 10
Level DSPQ1	from 11 to 30
Level DSPQ2	from 31 to 70
Level DSPQ3	71 or more

The method of assessment uses the parameters according to Table A.2.

Table A.2 – Power quality parameters

Parameter	Title	See
The ability to manage the power quality of the installation		
EX01	Dedicated internal PQ manager in the organization	A.3.2.1
EX02	Dedicated PQ expert	A.3.2.2
The ability to monitor the installation		
AM01	Ratio of the zones with PQ monitoring to total number of zones	A.3.3.1
AM02	Ratio of the uses with PQ monitoring to total number of uses	A.3.3.2
AM03	PQ monitoring granularity	A.3.3.3
AM04	Type of PQ instrument used	A.3.3.4
The ability to quantify the influencing factors that affect the DSPQ		
IF01	Equipment used to mitigate PQ events	A.3.4.1
IF02	Equipment installed which impacts PQ	A.3.4.2
IF03	External relevant variables which impact PQ	A.3.4.3
The ability to take readings from the quality points at regular intervals		
RI01	Method to collect the data	A.3.5.1
RI02	Interval of measurement	A.3.5.2
The ability to monitor and analyse the DSPQ		
AA01	Transients and short-term events according to Table C.1	A.3.6.1
AA02	Continuous voltage phenomena according to Table C.2	A.3.6.2
AA03	Continuous current phenomena according to Table C.3	A.3.6.3
AA04	Power-related events according to Table C.4	A.3.6.4

Parameter	Title	See
The ability to maintain the measurement system		
MS01	Frequency of verification of PQ monitoring system	A.3.7.1
MS02	Data management	A.3.7.2

A.3.2 Ability to manage the power quality of the installation

A.3.2.1 Parameter EX01: Dedicated internal PQ manager in the organization

This parameter takes into account if there is a dedicated internal PQ manager in the organization as illustrated in Table A.3.

Table A.3 – Parameter EX01

EX01 – Dedicated internal PQ manager in the organization	Points
Yes	10
No	0

A.3.2.2 Parameter EX02: Dedicated PQ expert

This parameter takes into account if an internal or external PQ expert performs the analysis of measurements as illustrated in Table A.4.

Table A.4 – Parameter EX02

EX02 – Dedicated PQ expert (internal or external)	Points
Yes	10
No	0

A.3.3 Ability to monitor the installation

A.3.3.1 Parameter AM01: Ratio of the zones with PQ monitoring to total number of zones

This parameter takes into account the ratio of the zones with PQ monitoring within the installation as illustrated in Table A.5. The assessment is based on the following equation:

$$AM01 = a \times 100/b$$

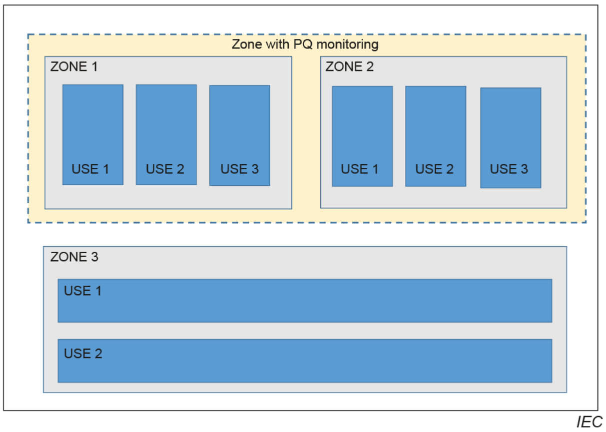
where

a is the number of zones with PQ monitoring;

b is the total number of zones.

Table A.5 – Parameter AM01

AM01 – Ratio of the zones	Points
< 50 %	1
≥ 50 %	2



Total number of zones
b = 3 zones

Number of zones with PQ monitoring
a = 2 zones

Ratio
a/b = 2/3 × 100 = 66 %

➔ AM01 ≥ 50 % ➔ 2 points

Figure A.2 – Parameter AM01: Example

A.3.3.2 Parameter AM02: Ratio of the uses with PQ monitoring to total number of uses

This parameter takes into account the ratio of the uses with PQ monitoring within the installation as illustrated in Table A.6. The assessment is based on the following equation:

$$\text{AM02} = a \times 100/b$$

where

a is the number of uses with PQ monitoring;

b is the total number of uses.

Table A.6 – Parameter AM02

AM02 – Ratio of the uses	Points
< 25 %	1
≥ 25 % and < 50 %	2
≥ 50 % and < 75 %	3
≥ 75 %	4

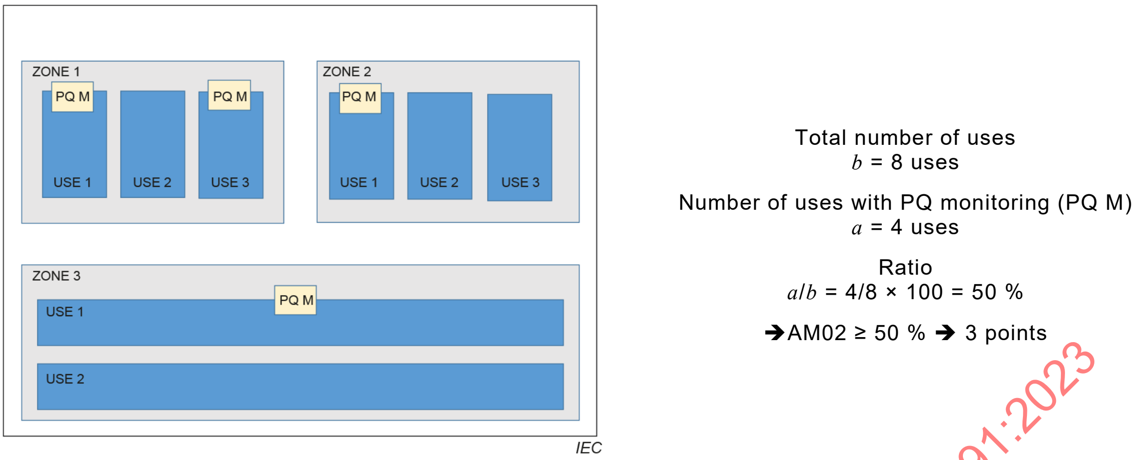


Figure A.3 – Parameter AM02: Example

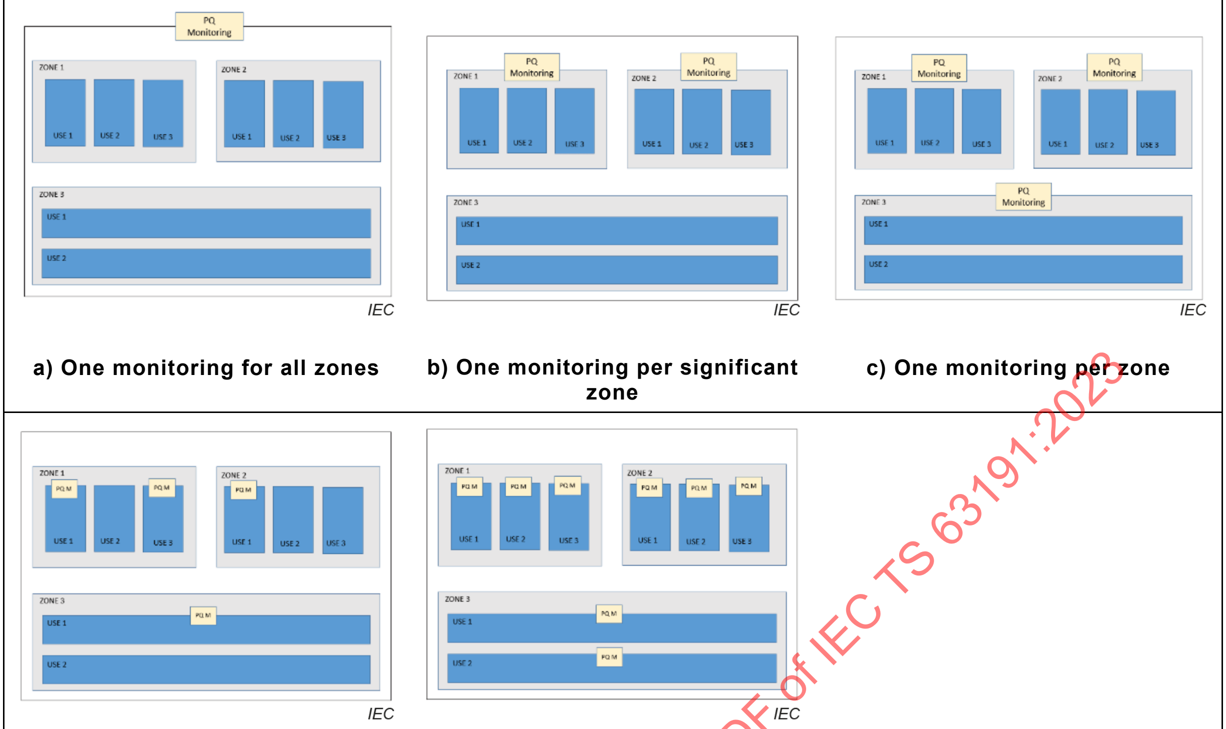
A.3.3.3 Parameter AM03: PQ monitoring granularity

This parameter takes into account the PQ monitoring granularity within the installation (see Annex B) as illustrated in Table A.7.

If several granularity levels are set, the points are summed.

Table A.7 – Parameter AM03

AM03 – PQ monitoring granularity	Points
One monitoring for all zones	1
One monitoring per significant zone	2
One monitoring per zone	4
One monitoring per significant use	6
One monitoring per use	10



a) One monitoring for all zones

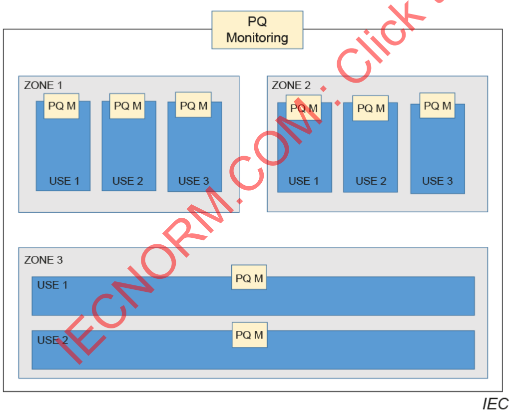
b) One monitoring per significant zone

c) One monitoring per zone

d) One monitoring per significant use

e) One monitoring per use

Figure A.4 – Parameter AM03



One monitoring for all zones: 1
+
One monitoring per use = 10
➔AM03 = 1 + 10 ➔ 11 points

Figure A.5 – Parameter AM03: Example

A.3.3.4 Parameter AM04: Type of PQ instrument used

This parameter takes into account the type of device to monitor PQ within the installation as illustrated in Table A.8. If different types of device are installed, the points for each type of device are summed as illustrated in Table A.9.

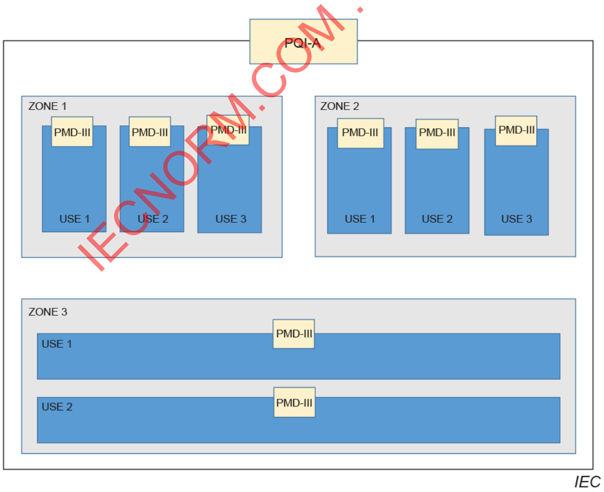
Table A.8 – Minimum required functions

Application	PMD-II	PMD-III	PQI-S	PQI-A[a]
PF	■	■		
THD_u, THD_i		■		
Power frequency			■	■
Magnitude of supply voltage			■	■
Supply voltage dips and swells			■	■
Supply voltage interruptions			■	■
Flicker				■
Supply voltage unbalance				■
Voltage harmonics				■
Voltage interharmonics				■
Mains signalling voltage				■

[a] PQI-A is mainly used for contractual or regulatory applications.

Table A.9 – Parameter AM04

AM04 – Type of PQ instrument used	Points
PMD-II	1
PMD-III	2
PQI-S	6
PQI-A	8



PQI A + PMD-III = 8 + 2 = 10

➔ AM04 = 10 points

Figure A.6 – Parameter AM04: Example

A.3.4 Ability to quantify the influencing factors that affect the DSPQ

A.3.4.1 Parameter IF01: Equipment used to mitigate PQ events

This parameter takes into account the additional equipment used to mitigate the events which impact PQ within the installation (see Annex D).

Table A.10 – Parameter IF01

IF01 – Equipment used to mitigate	Points
Power factor correction (PFC)	1
Harmonic filter	1
Static compensator (STATCOM)	1
Motor drives	1

A.3.4.2 Parameter IF02: Equipment installed which impacts PQ

This parameter takes into account the equipment installed that influences PQ within the installation (see Annex D) as illustrated in Table A.11.

Table A.11 – Parameter IF02

IF02 – Equipment installed	Points
Motors starters	−1
IT equipment	−1
Welders	−1
Switching equipment	−1
UPS (offline)	−1
Power electronics (e.g. motor drives, electric vehicle charging)	−1

A.3.4.3 Parameter IF03: External relevant variables which impact PQ

This parameter takes into account the external relevant variables that influence PQ within the installation as illustrated in Table A.12.

Table A.12 – Parameter IF03

IF03 – External relevant variable	Points
Bad quality of the energy delivered by utilities (not compliant with EN 50160, IEC TS 62749, IEEE 519)	−1
Disruptive neighbourhood sites [a]	−1
[a] A disruptive neighbourhood site is a site that contains one or more disruptive loads and a disruptive load is a load that causes an unexpected significant change in delivered power.	

A.3.5 Ability to take readings from the quality points at regular intervals

A.3.5.1 Parameter RI01: Method to collect the data

This parameter takes into account the method to collect the PQ data within the installation as illustrated in Table A.13.

Table A.13 – Parameter RI01

RI01 – Method to collect the data	Points
Only manual	1
Mix between manual and automatic	3
Fully automatic	4

A.3.5.2 Parameter RI02: Interval of measurement

This parameter takes into account the time interval of PQ data measurement within the installation as illustrated in Table A.14.

Table A.14 – Parameter RI02

RI02 – Interval of measurement	Points
month	1
week	2
day	3
hour	4
minute	5
Real time (for voltage events)	6

A.3.6 Ability to monitor and analyse the DSPQ

A.3.6.1 Parameter AA01: Transients and short-term events

This parameter takes into account the total level of disturbance of analysed short-term events in the installation according to Table C.1 as illustrated in Table A.15.

Table A.15 – Parameter AA01

AA01 – Short-term events monitoring	No	Yes
Voltage dips, interruption	0	4
Voltage swells	0	2
Voltage transient	0	2

If the event is monitored but not analysed, the number of points is equal to 0.

The parameter AA01 is the total of points obtained.

EXAMPLE

AA01 – Short-term events monitoring	No	Yes
Voltage dips, interruption		4
Voltage swells		2
Voltage transient	0	

Total of points for AA01 = 4 + 2 + 0 = 6.

A.3.6.2 Parameter AA02: Continuous voltage phenomena

This parameter takes into account the disturbance of analysed continuous voltage phenomena in the installation according to Table C.2.

Each event is weighted according to its influence on PQ as illustrated in Table A.16.

Table A.16 – Parameter AA02

AA02 – Continuous voltage phenomena monitoring	**No**	**Yes**
Voltage deviation	0	4
Voltage unbalance	0	1
Frequency deviation	0	1
Voltage flicker	0	4
Rapid voltage change	0	2
Voltage harmonics	0	4
Voltage THD (THD_u)	0	3

If the event is monitored but not analysed, the number of points is equal to 0.

The parameter AA02 is the total of points obtained.

EXAMPLE:

AA02 – Continuous voltage phenomena monitoring	**No**	**Yes**
Voltage deviation		4
Voltage unbalance	0	
Frequency deviation		1
Voltage flicker		4
Rapid voltage change	0	
Voltage harmonics		4
THD	0	

Total of points for AA02 = 4 + 0 + 1 + 4 + 0 + 4 + 0 = 13.

A.3.6.3 Parameter AA03: Continuous current phenomena

This parameter takes into account the disturbance of analysed continuous current phenomena in the installation according to Table C.3.

Each event is weighted according to its influence on PQ as illustrated in Table A.17.

Table A.17 – Parameter AA03

AA03 – Continuous current phenomena monitoring	**No**	**Yes**
Current THD (THD_i)	0	3

If the event is monitored but not analysed, the number of points is equal to 0.

A.3.6.4 Parameter AA04: Power-related events

This parameter takes into account the disturbance of analysed power-related events phenomena according to Table C.4.

Each event is weighted according to its influence on PQ as illustrated in Table A.18.

Table A.18 – Parameter AA04

AA04 – Power-related events	No	Yes
Power factor (PF)	0	3

If the event is monitored but not analysed, the number of points is equal to 0.

A.3.7 Ability to maintain the measurement system

A.3.7.1 Parameter MS01: Frequency of verification of PQ monitoring system

This parameter takes into account how often the PQ monitoring system is verified and optimized as illustrated in Table A.19.

Table A.19 – Parameter MS01

MS01 – Frequency of verification	Points
Yearly	1
Quarterly	2
Monthly	3

A.3.7.2 Parameter MS02: Data management

This parameter takes into account the ability to keep the history of data representing the key parameters of the installation as illustrated in Table A.20.

Table A.20 – Parameter MS02

MS02 – Data management	Points
≤ 6 months of history	1
> 6 months and ≤ 1 year	2
> 1 year	3
2 years	4

A.4 Results summary

The results summary is recorded in Table A.21

Table A.21 – Calculation table

Parameter	Title	Points
Ability to assess the power quality of the installation		
EX01	Dedicated internal PQ manager in the organization	
EX02	Dedicated PQ expert	
Ability to monitor the installation		
AM01	Ratio of the zones with PQ monitoring to total number of zones	
AM02	Ratio of the uses with PQ monitoring to total number of uses	
AM03	PQ monitoring granularity	
AM04	Type of PQ instrument used	
Ability to quantify the influencing factors that affect the DSPQ		
IF01	Equipment used to mitigate PQ events	
IF02	Equipment installed which impacts PQ	
IF03	External relevant variables which impact PQ	
Ability to take readings from the quality points at regular intervals		
RI01	Method to collect the data	
RI02	Interval of measurement	
Ability to monitor, understand and analyse the DSPQ		
AA01	Transients and short-term events according to Table C.1	
AA02	Continuous voltage phenomena according to Table C.2	
AA03	Continuous current phenomena according to Table C.3	
AA04	Power-related events according to Table C.4	
Ability to maintain the measurement system		
MS01	Frequency of verification of PQ monitoring system	
MS02	Data management	
Total		
PQ level according to Table A.1		

A.5 Typical level according to application

Not all applications require the same level of power quality and accordingly the same level of assessment. Table A.22 provides examples of a typical level to achieve for the given application.

Table A.22 – Typical level according to application

Application	PQ level
Chemical industry	3
Data centre	3
Prisons	3
Marine	3
Medical centre	3
Military	3
Nuclear plants	3
Public transportation (railways, airports, etc.)	3
Semiconductor plants	3
Water plants	3
Administration centre	2
Commercial centre	2
Education centre	2
Food manufacturers	2
Insurance	2
Mechanical engineering	2
Mining	2
Paper mill	2
Shopping mall	2
Steel mill	2
Waste plants	2
Wood plants	2
Bakery	1
Courts	1
Electric vehicle charging park	1
Hotels and restaurants	1
Research institute	1
Shipyard	1
Small shopping malls	1
Television	1
Residential	0
Small home office	0

Annex B
(informative)

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

Figure B.1 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.

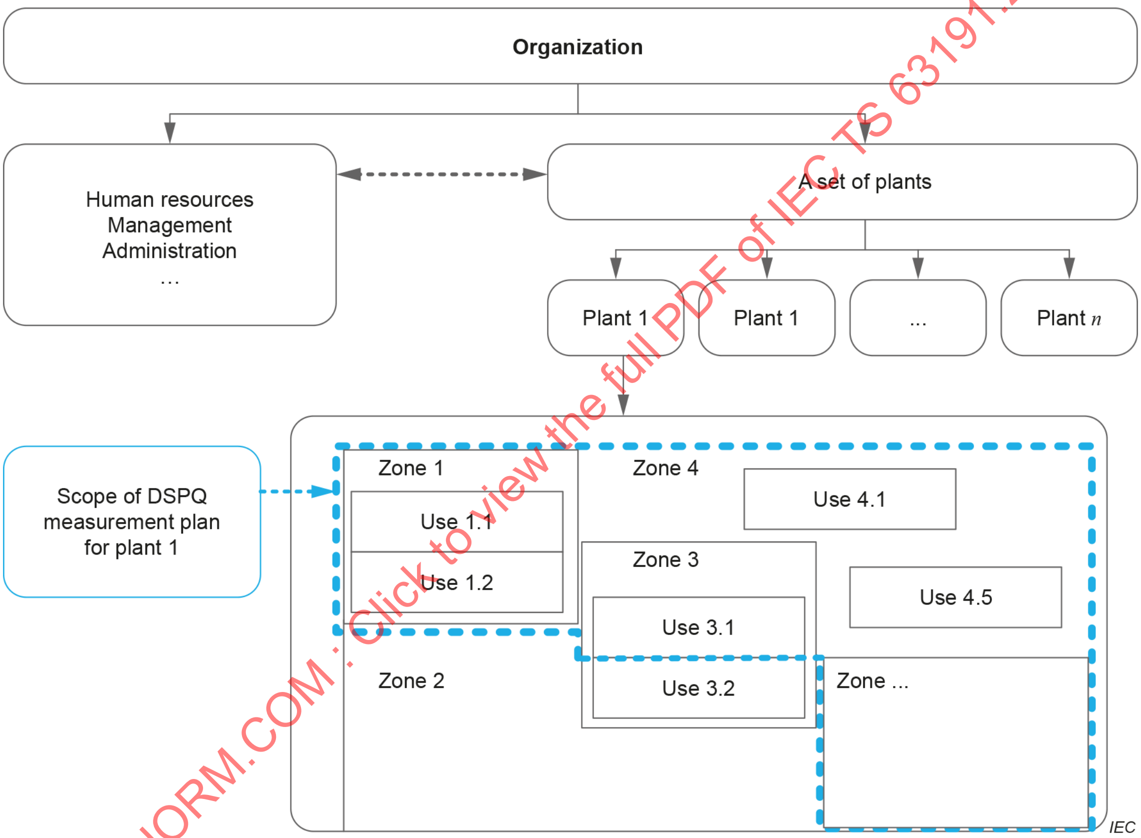


Figure B.1 – Example of the scope of a measurement plan

Annex C
(informative)

Disturbance levels on the demand-side PQ

C.1 General

Annex C defines 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 of 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 C.1, Table C.2, Table C.3 and Table C.4.

C.2 Transients and short-term events

Table C.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[a] 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.

Key

CBEMA: Computer Business Equipment Manufacturers Association

ITIC: Information Technology Industry Council

[a] 10/12 cycles: 10 cycles corresponds to 50 Hz nominal and 12 cycles to 60 Hz nominal; same correspondence for 25/30 cycles and 250/300 cycles.

C.3 Continuous voltage phenomena

Table C.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, class 1	IEC 61000-2-4, class 2	IEC 61000-2-4, 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, class 1	IEC 61000-2-4, class 2	IEC 61000-2-4, class 3
Frequency deviation	Limits	Δf < ±1 Hz	Δf < ±1 Hz	Δf < ±1 Hz
	References	IEC 61000-2-4, class 1	IEC 61000-2-4, class 2	IEC 61000-2-4, 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	$\Delta U_{steadystate}$ > 2 %, maximum 24 times per day ΔU_{max} > 5 %, maximum 24 times per day	$\Delta U_{steadystate}$ > 3 %, maximum 24 times per day ΔU_{max} > 5 %, maximum 24 times per day	$\Delta U_{steadystate}$ > 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 For Norway, see EN 50160:2010/A1:2015 Annex ZA (informative).	Working Group proposal, based on typical power quality measurement and IEC 61000-4-30

Events		Low disturbance	Medium disturbance	High disturbance
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 to 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 to 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 to 49]: 4,5 × (17/h) − 0,5
	Limits (Odd order multiple of 3)	Rank 3: 3 % Rank 9: 1, 5% Rank 15: 0,3 % Rank 21:0,2 % Rank [21 to 45]: 0,2 %	Rank 3: 5 % Rank 9: 1,5 % Rank 15: 0,5 % Rank 21:0,4 % Rank [21 to 45]: 0,3 %	Rank 3: 6 % Rank 9: 2,5 % Rank 15: 2 % Rank 21:1,75 % Rank [21 to 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 to 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 to 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 to 50]: 1 %
	References	IEC 61000-2-4, class 1	IEC 61000-2-4, class 2	IEC 61000-2-4, class 3
Voltage THD (THD_u)	Limits	THD_u < 5 %	THD_u < 8 %	THD_u < 10 %
	References	IEC 61000-2-4, class 1	IEC 61000-2-4, class 2	IEC 61000-2-4, 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.

C.4 Continuous current phenomena

Table C.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 can 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 non-linear 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.

C.5 Power-related events

Table C.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 60364-8-1:2019	IEC 60364-8-1:2019	IEC 60364-8-1:2019

Annex D
(informative)

Relationship between devices and electrical phenomena

Table D.1 summarizes the relationship between devices and electrical phenomena, with devices being either impacted, source or mitigation.

Table D.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**	**Lighting**	**Office devices (computers, printers, TV, etc.)**	**Cabling**	**Programmable logic controllers (PLC)**	**Inverter 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)							I				
	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		

Key

I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance

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

Table D.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	–

Key

I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance

Table D.3 – Variable speed drives

Disturbance	I / S / M	Explanation
Voltage dips	I	Variable speed drives are sensitive to voltage dips, which can 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.

Key

I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance

Table D.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 can lead to overloading, overheating and additional losses in transformers.
	S	Transformers require reactive energy and thus decrease power factor.
	M	–
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table D.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
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table D.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 can lead to oversizing or overload of the generators set.
	S	–
	M	–

Table D.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	–
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table D.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	Rapid voltage changes can cause visual discomfort because of changes in the illumination intensity.
	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	–
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table D.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 can 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	–

Key

I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance

Table D.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 can require oversizing of the neutral conductor.
	S	–
	M	–
Power factor	I	Poor power factor increases losses in the cables. It can lead to oversizing of the cables.
	S	–
	M	–
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Table D.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	–

Key

I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance

Table D.12 – Inverter 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	–
Key I: Impacted by disturbance; S: Source of disturbance; M: Mitigation device for disturbance		

Annex E
(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:

a) spread of equipment that disturbs and is sensitive to the electrical energy quality (power electronics, frequency converters, IT equipment or process control units);
b) increasing of the energy availability for better reliability, economic competitiveness, quality of services and data security;
c) 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;
d) demand for sustainable development and energy efficiency, which in their turn depend on the quality of the electrical energy;
e) 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 can be subject to disturbances carried by the distribution network. It can also generate internal disturbances that can impact its 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:

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

Consequence of grid evolution

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

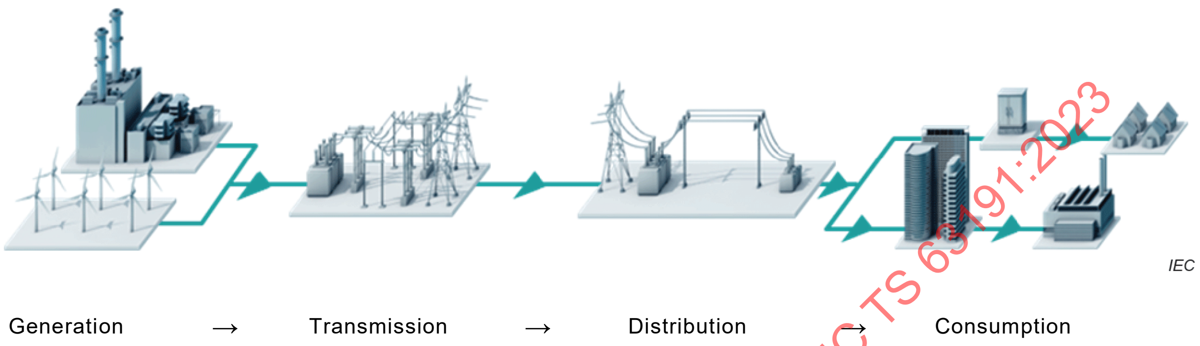


Figure F.1 – The old centralized grid

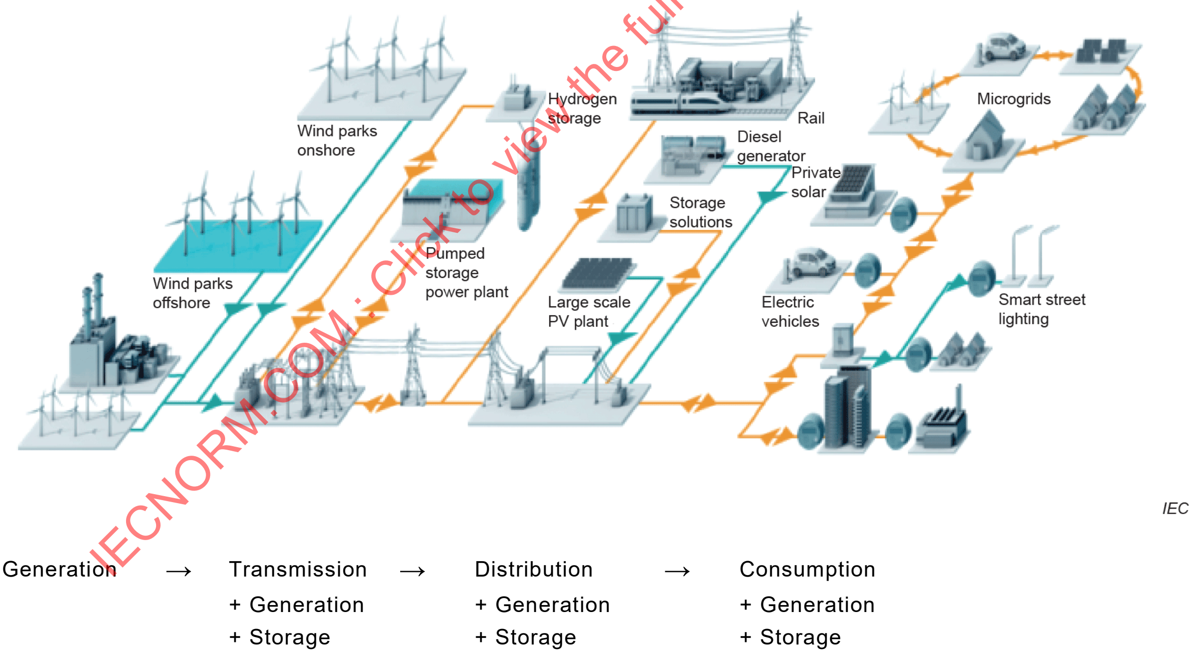


Figure F.2 – The new decentralized grid

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:

a) 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 F.3).

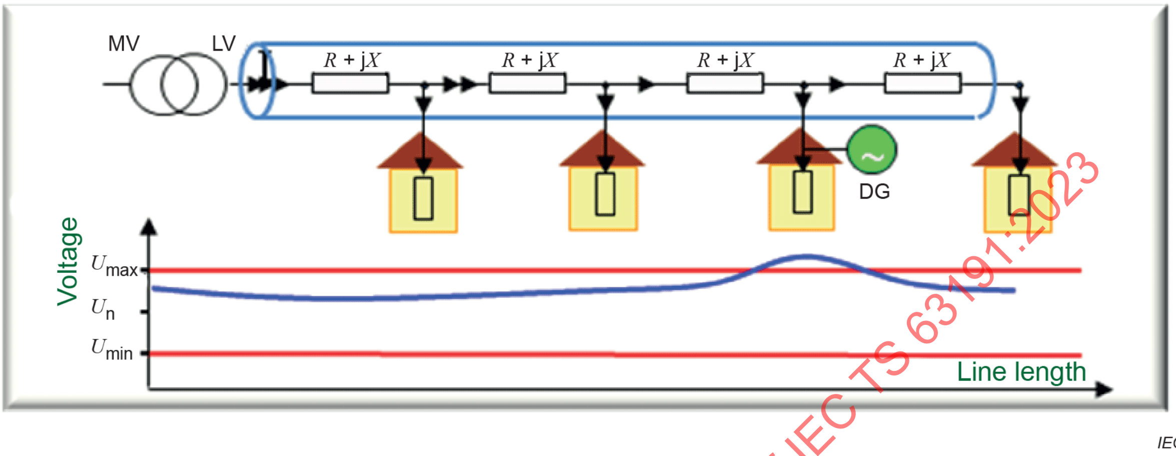


Figure F.3 – Example of consequences of a decentralized grid (DG)

b) 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 G
(informative)

Non-exhaustive list of relevant standards

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

Table G.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: Functional aspects – 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 for equipment with input current up to 16 A per phase 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 for PDS and machine tools Power converters: IEEE 519-2022 – 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 G.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 G.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.	