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TECHNICAL SPECIFICATION

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Power quality management –
Part 2: Power Quality Monitoring System

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CONTENTS

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POWER QUALITY MANAGEMENT –

Part 2: Power quality monitoring system

FOREWORD

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IEC TS 63222-2 has been prepared by IEC technical committee 8: System aspects of electrical energy supply. It is a Technical Specification.

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

Draft	Report on voting
8/1658/DTS	8/1674/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 http://www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63222 series, published under the general title *Power quality management*, can be found on the IEC website.

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- withdrawn,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.

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POWER QUALITY MANAGEMENT –

Part 2: Power Quality Monitoring System

1 Scope

This part of IEC 63222 defines technical requirements for designing a power quality monitoring system for public power supply networks. It is applicable for LV, MV and HV public power supply networks.

The design procedure of a power quality monitoring system (PQMS) generally includes the following four steps:

- Step 1: purpose and application analysis

  Analyse power quality monitoring (PQM) demand and define the purpose of PQM.

- Step 2: preliminary study

  Collect background information such as network configuration, the parameters of instrument transformers, e.g. the output levels and performance capabilities, attributes of loads or distributed generations (DG), communication conditions, budgets, and other restrictive conditions, and select the parameters to be monitored and monitoring sites according to corresponding principles.

- Step 3: system structure design

  Design the overall structure of the monitoring system according to the monitoring purpose based on the analysis of the advantages and disadvantages of various system structures.

- Step 4: detailed design of functional modules

  Design the function modules of data collection, communication, data storage, data processing and analysis in detail according to the functional requirements.

This document defines the main purposes of PQM and gives recommendations for preliminary study, such as how to select monitoring sites and monitoring parameters and whether the instrument transformer is suitable for monitoring. This document also classifies the PQMS structure and specifies the functional requirements of the modules such as data collection, communication, data storage, data processing and analysis.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61000-2-2:2002, *Electromagnetic compatibility (EMC) – Part 2-2: Environment − Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

IEC TR 61000-3-6, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of harmonic emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC TR 61000-3-7:2008, *Electromagnetic compatibility (EMC) – Part 3-7: Limits − Assessment of emission limits for the connection of fluctuating load installations to MV, HV and EHV power systems*

IEC TR 61000-3-13, *Electromagnetic compatibility (EMC) – Part 3-13: Limits − Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems*

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

IEC 61000-4-30:2015, *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques − Power quality measurement methods*

IEC TR 61850-90-17:2017, *Communication networks and systems for power utility automation - Part 90-17: Using IEC 61850 to transmit power quality data*

IEC 61869-6:2016, *Instrument transformers – Part 6: Additional general requirements for low power instrument transformers*

IEC 61869-11, *Instrument transformers – Part 11: Additional requirements for low power passive voltage transformers*

IEC TR 61869-103, *Instrument transformers – Part 103: The use of instrument transformers for power quality measurement*

IEC 62443 (all parts), *Industrial communication networks − Network and system security*

IEC 62586-1:2017, *Power quality measurement in power supply systems – Part 1: Power quality Instruments (PQI)*

IEC 62586-2, *Power quality measurement in power supply systems – Part 2: Functional tests and uncertainty requirements*

IEC TS 62749:2020, *Assessment of power quality − Characteristics of electricity supplied by public networks*

3 Terms and definitions

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

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

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

NOTE Terms are listed in alphabetical order.

3.1
flagged data
for any measurement time interval in which interruptions, dips or swells occur, the marked measurement results of all other parameters made during this time interval

[SOURCE: IEC 61000-4-30:2021, 3.5]

3.2
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

[SOURCE: IEC 60050-161:1990, 161-08-13]

3.3
point of common coupling
PCC
point in an electric power system, electrically nearest to a particular load, at which other loads are, or may be, connected

Note 1 to entry: These loads can be either devices, equipment or systems, or distinct network user's installations.

[SOURCE: IEC TS 62749:2020, 3.25, modified – "network" has been replaced by "system"]

3.4
point of connection
POC
reference point on the electric power system where the user's electrical facility is connected

[SOURCE: IEC 60050-617:2009, 617-04-01]

3.5
power quality
PQ
characteristics of the electric current, voltage and frequencies at a given point in an electric power system, evaluated against a set of reference technical parameters

Note 1 to entry: These parameters might, in some cases, relate to the compatibility between electricity supplied in an electric power system and the loads connected to that electric power system.

[SOURCE: IEC 60050-617:2009, 617-01-05]

3.6
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]

3.7
residual voltage
minimum value of $U_{\text{rms(½)}}$ recorded during a voltage dip or interruption

[SOURCE: IEC 61000-4-30:2021, 3.28]

3.8
time aggregation
combination of several sequential values of a given parameter (each determined over identical time intervals) to provide a value for a longer time interval

[SOURCE: IEC 61000-4-30:2021, 3.31]

3.9
voltage deviation
difference between the supply voltage at a given instant and the declared supply voltage

3.10
voltage dip
sudden reduction of the voltage at a point in an electrical system followed by voltage recovery after a short period of time from a few cycles to a few seconds

[SOURCE: IEC 60050-161:1990, 161-08-10]

3.11
voltage unbalance
in a polyphase system, a condition in which the magnitudes of the phase voltages or the phase angles between consecutive phases are not all equal (fundamental component)

[SOURCE: IEC TS 62749:2020, 3.47]

4 Purposes and applications analysis

The most important step in the design of a PQ monitoring system is clear identification of the purpose for PQ monitoring, which is crucial for the selection of monitoring sites, the selection of monitoring parameters, monitoring system structure and requirements of functional modules, etc.

The following main purposes for PQ monitoring can be distinguished from the present PQM practices:

- Compliance verification

  Compliance verification compares a defined set of power quality parameters with limits given by standards, contracts or regulatory specifications. The verification results are reported externally to promote power quality management. It includes typical tasks such as verification of compliance with the connection contracts for a connected user, or verification of compliance with regulatory specification for a system operator. Compliance verification is usually done for individual sites and provides qualitative results. It can also be applied to multiple sites by using appropriate aggregation.

- Performance analysis

  Performance analysis is mainly undertaken by system operators to assess average power quality levels in a grid. The analysis results can be used to determine long term trends by system operators and provide support for strategic planning, asset management and benchmarking, etc. Performance analysis is usually done for multiple sites but can be applied to single sites as well. It provides quantitative results (indices), which can be selected flexibly and it is not mandatory to follow specific standards. Benchmarking compares one or more indices for different sets of sites and is part of performance analysis.

- Site characterization

  Site characterization is used to describe PQ at a specific site in a detailed way. It includes typical tasks such as to predefine the expected power quality for a potential customer or to assess and verify power quality once the customer is already connected to the grid. It is important to know the power quality at a particular site, in particular to predict the effect of a new non-linear, unbalanced or intermittent load, and subsequently survey the ability of the site to comply with the contractual constraints.

- Troubleshooting

  Troubleshooting is used to diagnose power quality related problems such as system harmonic resonance, the abnormal interruption of the customer production process, equipment malfunction, etc. A long term PQM campaign by permanent monitoring equipment can provide more useful information for troubleshooting, especially for process interruptions caused by voltage dips. Typically, raw unaggregated power quality measurement data are most useful for troubleshooting, as they permit any type of post-processing preferred.

- Advanced applications and studies

  Advanced applications and studies are relevant for purposes of different aspects from both system operator's side and end user's side, e.g. how to improve the efficiency of system operation, how to promote end user's immunity capability, etc., it includes more specific measurements and deep analyses that are often not part of the daily business. Typical applications and studies include fault location, signature analysis and studies of propagation of power quality phenomena.

5 Preliminary study

5.1 Background information collection

The following background information should be collected before the design of the PQMS:

- Power supply network configuration to be monitored

  The configuration of the power supply network to be monitored such as power grid topological structure (e.g. radial or meshed networks), three-phase or single-phase, short-circuit powers, the categories of feeders available for monitoring (e.g. urban, semi urban or semi-rural, rural), and the parameters of instrument transformers, e.g. the output levels and performance capabilities, should be collected, which can be used for the selection of monitoring sites.

- Attributes and information of loads or DGs

  The attributes and information of loads or DGs should be collected, such as the access location, voltage level, and installed capacity of wind farms, solar plants, electric railways, arc furnaces, energy storage power stations, and electric vehicle charging infrastructure or stations, etc.

- Existing communication condition

  Understanding the existing communication condition available for PQ monitoring is very important. The communication between PQ equipment and data centre will be based on the available conditions. Analysis should also be made to carry out whether the existing communication condition is enough and feasible to be used for the operation of future PQMS, otherwise measures should be taken to improve it in advance.

- Constraints

  Constraints should be clearly identified in advance, e.g., budget, limited condition at present, etc. The PQMS designing should be subject to these factors.

- Future development anticipation

  Understanding system development planning in short term, medium term and long term is crucial for PQMS designing. Technically and economically, PQMS designing should be based on and adapted to power supply system planning, especially for PQMS structure selection, data storage strategy selection and configuration of different kinds of function services, although it can be updated and upgraded in the future step by step.

  Generally, the anticipation should not only focus on the development of the supply system topological structure, but also on the trend of power station digitalization and the connection scale of power-electronic interfaced renewable energy.

5.2 Selection of monitoring sites

The selection of monitoring sites is strongly related to the power grid architecture and also to monitoring purpose. The principles for selecting monitoring sites for different monitoring purposes are given below.

- Compliance verification

  The monitoring sites should be set up in accordance with the standards, the contracts or the regulation that the compliance verification is based on. In most cases, the compliance verification only requires voltage measurements, and the monitoring sites should be at customer's POC or PCC. When the compliance verification additionally requires current measurements, the monitoring sites should be located somewhere along the feeder supplying the customer (either at customer's POC or at the substation busbar to which the feeder is connected).

- Performance analysis

  The system performance analysis can be scalable by focusing on the part of certain area, monitoring at only a limited number of sites from all sites will be sufficient. Statistical methods are recommended to select partially representative site samples in order to achieve an acceptable accuracy and to reduce the costs.

- Site characterization

  For the background PQ characterization of the site that a new customer may connect to, the monitoring sites should be as close as possible to the customer's future connection point, such as the nearest substation busbar or any other close customer where PQ is already monitored. For performance verification of existing customers, the monitoring sites should be at customer's POC or PCC.

- Troubleshooting

  The monitoring sites should be as close as possible to the location where the PQ problem or customer complaints is reported, such as the terminal of the connected equipment that failed, the PCC of the customer who made the complaints or the outgoing feeder in the substation. Additionally, disturbance propagation analysis may be needed, and relevant sites accordingly may be selected.

- Advanced applications and studies

  PQ monitoring sites should be set up according to the specific tasks of advanced applications and studies. For example, for signature analysis of specific equipment, the monitoring sites should be as close as possible to the concerned equipment, such as a transformer branch or capacitor branch.

5.3 Selection of monitoring parameters

The selection of monitoring parameters mainly depends on the monitoring purpose. The following factors need to be considered to determine the monitoring parameters:

- Power quality indicators to be monitored: such as frequency, root-mean-square (RMS) voltage, voltage unbalance, voltage harmonics, voltage interharmonics, voltage transients and voltage dips and swells.
- Voltage or current to be measured: generally, it is required to measure voltage, the need to measure current should be determined according to the monitoring purpose aforementioned.
- Time interval and data processing method: time interval and aggregation method different from that defined in IEC 61000-4-30 may be needed for monitoring purposes such as troubleshooting and site characterization. Time interval less than 10 minutes for aggregation may be selected. If it is needed, the maximum/minimum/average RMS value may be recorded in the selected aggregation time duration.
- Voltage dip and swell are characterised by retained voltage and time duration according to IEC 61000-4-30. As an advanced option, it is recommended to record voltage and current waveforms during voltage dip and swell. A pre-windows and a post window during the event may be included according to the performance of PQ analysis requirement.

The details of the selection of monitoring parameters for different monitoring purposes are given below.

- Compliance verification

  The parameters to be monitored depend on the standard, the contract or the regulation which is to be applied. The most common parameters required are frequency, RMS voltage, voltage unbalance, voltage harmonics and voltage dips and swells.

  Most standards or recommendations only call for compliance with respect to voltage disturbances, e.g. IEC TR 61000-3-6, IEC TR 61000-3-7 and IEC TR 61000-3-13. Some national regulations and grid codes require measurement of current parameters as well as voltages.

  According to IEC TS 62749, the aggregated values (3 second values, 10 minute values and 2 hour values) are required for continuous PQ phenomena assessment. Residual voltage and duration combined with the RMS voltage variation shape are required for single event assessment.

- Performance analysis

  For performance analysis of a system with a large number of sites, it is generally required to monitor only voltage disturbances. Generally, 10 minute values are sufficient to obtain an accurate picture of the performance across a grid. Weighting rules may be used applying both to statistical indices and events in order to obtain results that are universally comparable. Refer to IEC TS 62749:2020, Annex B for detailed information on weighting rules.

- Site characterization

  For characterization of a particular site that a new customer may connect to, the parameters to be monitored depend on the standard used and the nature of the customer's load. For non-linear and fluctuating loads such as electrified railways, arc furnaces, rolling mills, parameters such as voltage unbalance, voltage harmonics and flicker should be monitored. For electric vehicle charging facilities, variable speed drives or renewable energy generations with power electronics as interface, parameters such as voltage harmonics up to 40th (60 Hz system) or 50th (50 Hz system) and corresponding interharmonics should be monitored. When it is needed, frequencies up to 150 kHz may be measured. For voltage sensitive loads such as automatic production lines, parameters such as supply voltage variations, voltage dips and voltage swells should be monitored.

Generally, 10-minute values are sufficient. However shorter intervals (e.g. 3 seconds, 1 minute) may be used for more details depending on the nature of the customer's loads.

- Troubleshooting

  In order to troubleshoot specific problems, e.g. equipment malfunction or the abnormal interruption of the customer production process, the parameters to be monitored depend on the problem being investigated (e.g. flicker at an arc furnace or rolling mill) and can include transients. It is recommended to use shorter interval values, such as 3 second values or 1 minute values. Particularly in the case of transients, raw unaggregated measurement data, e.g. waveform data, are most useful. Waveform data triggered by PQ parameters related to the problems and even continuous recording of waveforms may be required.

  In this case, both voltage and current are required to be monitored, since combined voltage and current can help to determine if the disturbance comes from upstream or downstream. In some cases, the phase angle may be needed.

- Advanced applications and studies

  For the purpose of advanced applications and studies, the parameters to be monitored depend on the specific application. For example, in the case of studying propagation of PQ phenomena, the parameter of interest (e.g. flicker, unbalance and harmonics) needs to be monitored in a consistent and comparable manner on each system. Many applications require the measurement of currents as well as voltages (e.g. fault location, signature analysis).

5.4 Voltage Transformer (VT)/Current Transformer (CT) characteristics analysis

The frequency response of instrument transformers have a significant impact on the overall accuracy of the PQ measurements, especially for harmonics. Therefore, attention shall be paid to the accuracy and frequency bandwidth of instrument transformers. The accuracy requirements of instrument transformers should be determined according to the monitoring purposes. For example, a higher accuracy may be necessary for compliance verification rather than for performance analysis. Refer to Annex A for detailed characteristics of each kind instrument transformers.

NOTE The impact on the accuracy of instrument transformers in case of multiple intelligent electronic devices (IED) connecting to a single VT/CT cannot be negligible.

5.5 Data sources

The data sources mainly include: fixed instruments, portable instruments, data files and other devices or systems with PQM functions. The selection of monitoring data sources depends on monitoring purposes and cost constraints.

- Fixed instruments

  Fixed instruments are used for long-term, continuous PQM, which helps to obtain PQ parameter variations within a year or a week and get information on relatively rare voltage events such as voltage dips and swells. Fixed instruments can be used for various monitoring purposes, especially where it is necessary to monitor voltage dips and swells.

- Portable instruments

  Portable instruments are used for temporary and short-term PQM. The monitoring using portable instruments shall be over a time period sufficient to determine the normal characteristic operating cycles at the site. In general, one or two full business cycles may be sufficient for this purpose. The business cycle is one week in the case of most commercial or residential loads, but it can be as short as a few hours for an industrial installation.

  Portable instruments can be used for performance analysis with a rotating approach, where a monitor stays at a site for a specific period of time to capture a sample of measurements and then is moved to another site.

- Others

  Other data sources include:

  a) Other devices that can provide monitoring data, such as smart meters, relays, controllers, remote terminal units (RTU), phasor measurement units (PMU). Especially for performance analysis, these devices can provide useful information due to their wide applications in future power grids.

  b) PQ data files, such as power quality data interchange format (PQDIF) files and COMTRADE files.

  c) Other systems that can provide monitoring data, such as supervisory control and data acquisition (SCADA) system, wide area measurement system (WAMS) and the main station system for the access of smart meters, RTUs and other devices.

The requirements of monitoring instruments should be determined according to the monitoring purpose. For example, IEC 61000-4-30 Class A compliant instruments should be used for compliance verification according to standards or regulatory specifications. IEC 61000-4-30 Class A or S compliant instruments can be used for performance analysis. The performance of monitoring instruments should comply with IEC 62586-1 and IEC 62586-2.

6 PQ monitoring system structure and functions

6.1 General

The functions of the PQMS generally include data collection, communication, data storage, data processing and analysis, system maintenance, which can be presented as function modules. Figure 1 shows the various modules of the system and their main functions.

The above-mentioned functions can reside in various hardware or software components of the system. Note that these functions do not necessarily always match up with separate devices, as several functions can be performed by a single device. As an example, a high-performance PQI can collect the monitoring data, store it temporarily, analyse it and transmit it through the network, which can be called a simple PQ monitoring system.

Logically, several services undertaking the same function may be needed for large scale monitoring system.

PQMS can be based on common communication infrastructure, required for other systems like power management system (PMS) or energy management system (EMS).

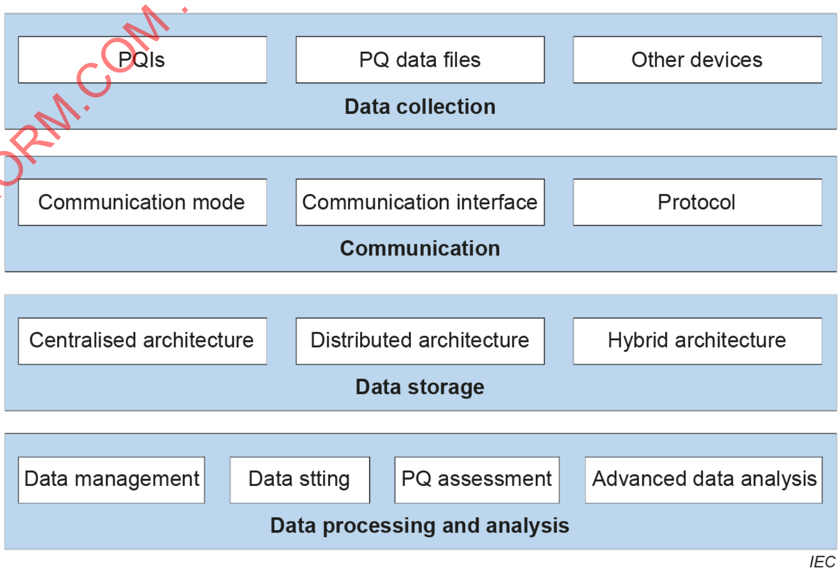

Figure 1 – Function modules of power quality monitoring system

The structure and function of the PQMS are closely related to the monitoring purpose. For example, for the purpose of compliance verification at individual sites, a PQ monitoring system consisting of only a few PQIs is sufficient. For the purpose of performance analysis at multiple sites in a grid, a complicated PQ monitoring system containing multiple servers and software may be required. Figure 2 shows the structure of a typical PQ monitoring system for the purpose of performance analysis.

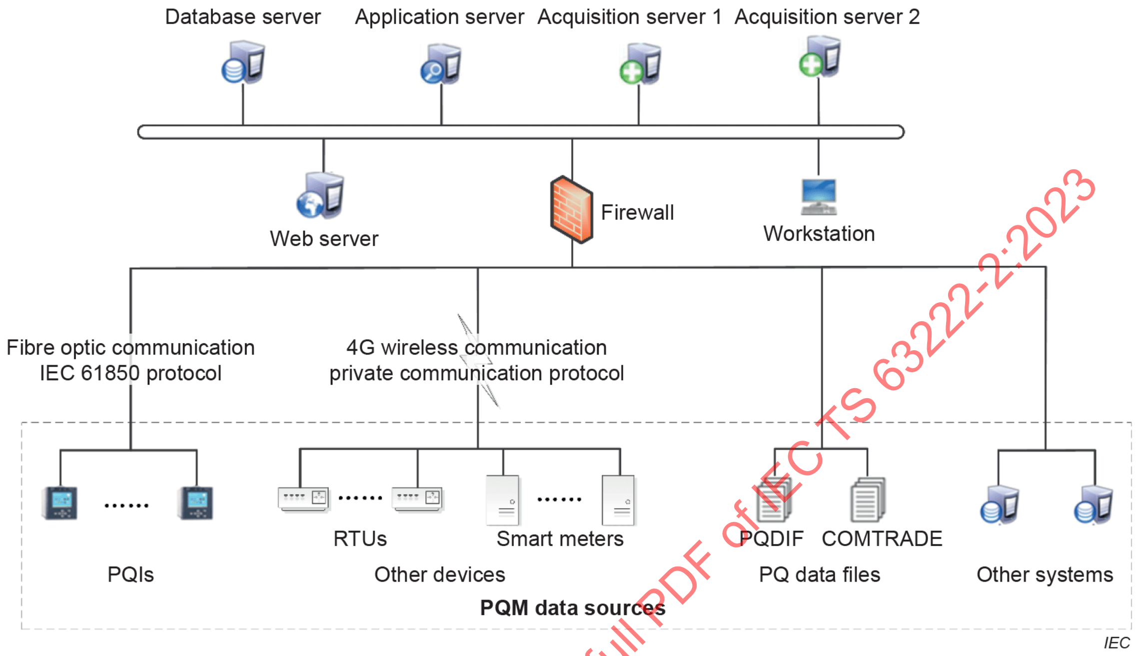

Figure 2 – Structure of a typical power quality monitoring system

Routine maintenance work should be performed to ensure the system availability, including monitoring site management, access management, system configuration, communication management, data backup, etc.

6.2 Function modules

6.2.1 Data collection

The principles of data collection from data sources (e.g. PQIs, smart meters) to PQ monitoring system rely on the relevant purposes. For general PQ assessment or benchmarking, data record of PQ parameters defined in IEC TS 62749 should be transferred. For troubleshooting or advanced data application, thresholds triggered waveform, 150/180 cycle record, or aggregation duration less than 10 min record may be collected.

If the PQI is used for long term PQ assessment, in order to reduce the massive data, only the resultant evaluation conclusion can be transferred.

6.2.2 Communication

In order to ensure the reliable transmission of monitoring data between the monitoring data source and the monitoring system, the communication module should be designed according to the monitoring purpose and considering sufficient flexibility, and the communication mode, communication interface and protocol should be selected reasonably. Details of communication and protocol are given in Clause 7.

6.2.3 Data storage

The function of data storage module is to store the monitoring data in a suitable way so that it can be accessed at any time when needed. There are three different data storage strategies: centralized, distributed and hybrid. Different data storage strategies should be adopted based on monitoring purposes. For example, when the monitoring purpose is performance analysis, there is no need to upload all PQ monitoring data to the central database for a monitoring system with hundreds of monitoring sites since it will be rarely used. In this case, it is recommended to adopt the hybrid storage strategy, that is, only the most useful data (e.g. statistical data) are uploaded to the central database, and the detailed data (e.g. waveforms, harmonics, interharmonics) can be stored in the distributed database. See 6.3.3 for details of data storage.

6.2.4 Data processing and analysis

The function of data processing and analysis module is to process and analyse a large amount of monitoring data collected according to monitoring purposes and present the analysis results to system users in an easy-to-understand manner, including power quality assessment, graphics or table display, data statistics, etc. This module should also have data management functions, such as data backup, data quality management, missing data checking, etc. Details of data processing and analysis are given in Clause 8.

6.3 System structure

6.3.1 General

System structure is an important aspect that need to be considered in the design of a PQMS. There are many types of PQMS structures, and classifications of the system structure are needed. Two commonly used software architectures client/server and browser/server are discussed in 6.3.2. According to the location of data storage, the monitoring system architecture can be classified into three types: centralized, distributed and hybrid. These types of architectures are discussed in detail in 6.3.3.

6.3.2 Brower/Server (B/S) and Client/Server (C/S) architecture

Client/server architecture is composed of clients initiating requests for services and servers providing that function or service. The client relies on sending a request to another program in order to access a service made available by a server. The server runs one or more programs that share resources with and distribute the work among clients. By reasonably allocating tasks to the client and the server, the advantages of the hardware resources at both ends can be fully utilized and the communication consumption of the system is reduced. Therefore, the PQMS adopting client/server architecture has fast response speed and strong data processing capability, which is more suitable for power quality professionals to carry out complex data processing and analysis tasks, such as fault location and signature analysis based on monitoring data.

Browser/server architecture adopts a three-tier structure, and an intermediate layer, namely a web server layer, is added on the basis of client/server architecture. There is no need to install special application software such as the client, and only a computer with a browser is needed for monitoring, which reduces the requirements for the client. The PQMS adopting browser/server architecture is flexible, easy to integrate and expand and easy to maintain. It only needs to change the webpage to realize the simultaneous update of all users. Therefore, it can be used in most monitoring applications, such as compliance verification and performance analysis.

6.3.3 Centralized and distributed architecture

The location of the overall database makes the difference between a centralised and a distributed architecture: for a centralised approach, any information recorded by the PQIs is uploaded to a central database for further storage and analysis; on a distributed architecture each PQI holds its own database. When the PQMS initiates a query, it can be executed by just a database engine (i.e. centric approach), while on the distributed architecture it is forwarded to the corresponding PQI.

The distributed approach was established mainly because for most of the time (e.g. 99,9 %), very detailed power quality data is rarely used. Indeed, waveforms and even the value of any single harmonic is not important when dealing with a system as a whole, but just for detailed fault analysis. By using the distributed concept, there are huge storage savings on commercial clouds and there is a better use of the communication links. Moreover, parallel requests can be forwarded to every single PQI at the same time, behaving as a very powerful and fast distributed database.

Indeed, centralised databases made of many servers running in parallel are becoming very popular (e.g. NoSQL databases), which although similar to distributed architecture, have inferior optimisation (since data is not close to where it is generated).

Figure 3 and Figure 4 are very synthetic examples of both architectures:

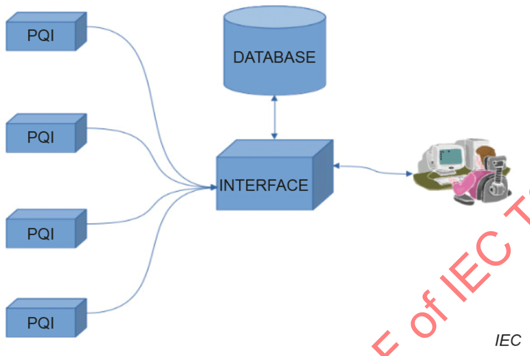

Figure 3 – Centralised architecture

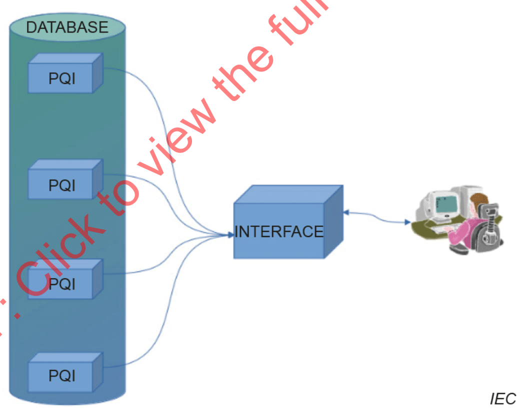

Figure 4 – Distributed architecture

In the real world, a hybrid architecture seems the optimal choice, holding a central database for average and statistical data, while waveforms, specific harmonics and interharmonics can be kept in the distributed database. Another possibility is to hold a single database instance in every substation, thus freeing up every PQI of running a database. A detailed example of a hybrid architecture is depicted in CIRED paper "Enel global solution for power quality monitoring and analysis".

7 Communication and protocol

7.1 General

There are different requirements for the reliability, bandwidth and latency of the communication network for different monitoring purposes. For example, for the purpose of troubleshooting or advanced applications, a large amount of data may be transmitted, so it is recommended to use a wide bandwidth communication network such as a fibre optic communication network or a 4G cellular network. For the purpose of performance analysis, the communication should have high reliability, otherwise it may cause the missing monitoring data at multiple monitoring sites, and it will take a lot of resources and time to recollect the missing data. On the other hand, there are many protocols that can be used for the transmission of monitoring data, such as

IEC TR 61850-90-17, COMTRADE and PQDIF. The choice of the protocol mainly depends on the specific monitoring requirements. Therefore, sufficient flexibility should be considered based on different purposes when designing the communication function module of the PQ monitoring system.

7.2 Communication

7.2.1 Communication mode

Long-range wireless communications are usually provided by cellular networks. There are also other long-range wireless links (e.g. LoraWAN), although they are mostly intended for IoT networks, thus with very reduced bandwidth. Bear in mind that PQIs are able to record hundreds or thousands of variables plus waveforms, thus this latter connectivity is not appropriate. However cellular networks do nowadays provide good bandwidth and even low latency, so they have become appropriate for many power quality applications.

Using wireless or wired communication is usually a trade-off between cost and performance. Cellular connections have become inexpensive, although still unreliable, and its latency tends to be higher than a comparable copper or fibre connection. On the other hand, due to the mass adoption of fibre optics, wired connections are increasingly reliable and they do have a very good bandwidth and latency, however they are usually more expensive.

In general, a non-wireless communication method might be needed for those applications that require a permanent, reliable and low-latency connection, such as distributed/hybrid architecture or online management of power quality. In contrast, a cellular link could be an acceptable choice for centralised architectures without any online management of power quality. For portable equipment it would be also the right choice unless manual downloading of data is preferred.

7.2.2 Communication interface

Serial links were the most widely adopted in the past when PQIs were very expensive devices with very few hardware resources and communication infrastructures were scarce and slow. Connectivity is essential and deployment of large-scale sets of PQIs are very common. Thus, PQIs embedding just serial connectivity is a serious drawback. However serial links are still the most common choice within substations for SCADA interfacing, allowing a PQI to behave also as a digital multimeter or even an energy revenue meter (thus lowering the overall investment in every substation).

NOTE However, this is no longer the case and PQIs are far more powerful, incorporating embedded computers which are more advanced compared with desktop PCs used in older PQIs.

On the other hand, IP connectivity is offered almost for free. This can be provided by common Ethernet interfaces according to IEEE 802.3x standards, wireless computer network according to any of IEEE 802.11 set of standards or even inbuilt cellular modems or routers. In any case the key issue is the capability of single-addressing of any PQI and simultaneous communication through the same hardware layer, which could be difficult using a standard serial link.

It is worth noting that in order to address every single PQI, IPv6 is a far better choice than IPv4. Although it is not widely used yet, it is recommended that PQIs do have dual IPv4/IPv6 stack so they can be ready for future upgrades of telecommunication networks (bear in mind that PQIs may last decades as any other utility infrastructure).

USB interfaces are mostly employed as a local interface for configuration or as an expansion, allowing easier hardware upgrades (e.g. serial ports, modems, etc.).

7.3 Protocol

Each data protocol is intended for different applications. In IEC TR 61850-90-17, three main use cases are addressed:

- Use case #1: online request of power quality measurements. The main goal is a SCADA/real-time control of the most common PQ quantities (e.g. harmonics, flicker, unbalance, etc.).

- Use case #2: sending of power quality events and limit violations. It is intended for almost instantaneously receiving information or detailed parameters of voltage dips, swells, interruptions or even sustained overvoltages and undervoltages.
- Use case #3: retrieval of power quality records, most commonly for compliance and fault analysis.

Use cases #1 and #2 are properly solved by IEC TR 61850-90-17 by using specific logical nodes (see IEC TR 61850-90-17:2017, 6.4 and 6.5): type M for online requests and type Q for sending events and violations. IEC 61850 series strongly relies on IP communication. For both cases, a reliable connection is mandatory, although latency is not critical. However, as already stated in 7.2.1, this can only be accomplished by a wired link, either copper- or fibre-based.

Use case #3 is also managed by IEC TR 61850-90-17, although its methodology can be greatly improved by using alternative protocols and architectures. Indeed, this document defines a set of logical nodes (type-Q) which are able to build and store power quality statistics, so they can be directly queried by central systems in order to perform a compliance analysis. Moreover type-R nodes (e.g. RDRE) indicate that new fault records are available for downloading. These fault records are stored in COMTRADE format, but in any case, they need to be downloaded by using any either MMS, FTP or even SFTP protocol.

COMTRADE is defined in IEEE/IEC C37.111-2013 is widely used by electronic protective relays and it is de-facto standard for fault recording. End users are familiar with COMTRADE and there are many software viewers available. IEC TR 61850-90-17 addresses the COMTRADE format for managing waveform recordings, which are mostly used when dealing with customer complaints and fault analysis.

IEC TR 61850-90-17 also addresses the binary format PQDIF, which is described in IEEE 1159.3-2019, as the target format for transferring power quality data to central locations. Although this format is well defined and is able to pack into a single file a complete set of power quality data (even waveforms), it does not cover the distributed architecture already described within 6.3.3. Indeed, it is usually very different to the internal format within a single PQIs, thus it usually involves a strong encoding effort by a single PQI (which needs further decoding by the central system in order to make it usable).

On the other hand, there is a major tendency across PQI manufacturers to use web services (such as HTTP REST) which relieves the PQI of unnecessary encoding tasks. Moreover, there is no need to upload the complete set of power quality records to a central location, but just the most relevant data, keeping less important data in the PQI for unlikely future analysis. Another important advantage is the straightforward integration with common IT networks, which are increasingly reliant on web services. Last but not least, these features are suitable for both a hybrid and a centralised architecture.

Several utilities have started to standardise the semantics and contents of these web services, thus allowing full interoperability and lower IT integration costs. Refer to ENEL Global Standard GSTQ002:2016.

In short, it is highly recommended that any PQMS always provide web services for downloading power quality records. On a secondary layer, if power quality is part of the SCADA architecture, then it should also be integrated into the most important logical nodes and functionalities described within IEC TR 61850-90-17.

8 Data storage and management

8.1 Data storage

Data can be kept either internally or externally to the PQI. In the first case it can remain as binary files requiring further uploading to a central site for later processing, or as internal database information that can be accessed at any time.

In order to make complex analysis, data should be managed by automatic tools and/or databases. Data management by hand by the end user is not scalable and prone to failures. Thus, data should be kept on live databases or populated through interfaces that behave as such. For instance, data might be made of flat text files within a cloud, but automatic tools and interfaces for querying such data should be mandatory. Moreover, a distributed or hybrid architecture should be transparent to the end-user, who has no requirement to know the location of the data, only what can be done with it. The most common file formats such as Microsoft Excel's worksheet format (XLS) or Comma Separated Values (CSV), should be the output of those automatic query tools, not the core itself.

Data storage capacity mainly depends on the number of monitoring sites, the storage period and the time interval of aggregated values (such as 3 seconds, 1 minute or 10 minutes). Especially for a monitoring system with a large number of sites that adopts the centralised architecture, the data storage capacity will be huge. The storage period for PQ aggregated data in the central database relies on the purpose for what they will be used.

8.2 Data management

8.2.1 Data backup

If the PQMS solution is centralised, then off-the-shelf backup IT solutions can be used. If distributed or hybrid solutions are used, then it makes no sense for a full backup of every single node since it would mean that we are behaving as a pure centralised architecture. In such a case it makes more sense to keep sensitive data (such as key statistics and events lists) in a central location, with less important data is kept (such as specific harmonic or interharmonic trends and waveforms) in every node.

8.2.2 Data quality management

Some PQ data quality issues are simple/trivial, yet surprisingly common. Sometimes these can effectively ruin the entire measurement campaign or necessitate a re-visit by engineers to the installation site. For common set-ups, particularly in multiple sites an installation procedure and check list, are recommended to avoid some of these simple but high-impact errors.

A common PQ data quality issue is incorrect time stamping. This occurs when the clock source used in the PQ analyser runs slow or fast, leading to difficulties in associating PQ events with other PQ and system data.

Installation errors such as incorrect phase connection can cause confusion in analysis. It is important that proper installation test procedures are put in place to ensure these errors are avoided.

Missing data can occur due to the PQ analyser, suffering a power energization fault, resetting, or temporarily stopping data collection. Where data is recorded with a time stamp and/or record sequence number, this can be detected and flagged.

Overloads and saturations in the data can cause confusion. For example, if the time domain data saturates because it is over ranging near the peaks of the waveform, this will cause an apparent flat top (and bottom) to the waveform where the peaks are "clipped" by the over-ranging ADC. If a DFT is applied to this clipped waveform data, a rich set of incorrect harmonics will result causing confusion to the instrument operator, especially if the time domain waveform data is not available or not viewed. It is important that correct ranging for VT/CTs is applied and this is verified during installation.

VT and particularly CT ratios also cause confusion. The installation should verify signal levels and check the PQ indicator reports the expected levels when the CT/VT ratio factors are applied.

8.2.3 Missing data checking

When dealing with power quality records, it is very likely to find data gaps, most of the time for 10-minute periodic records. In such a case, batch processes should run periodically for detecting such gaps and querying the device for its retrieval. This is more frequent on centralised architectures. Nevertheless, it also may happen on distributed topologies, for instance due to power supply failures. In any case, it should be clearly addressed by central batch processes (if not, statistics could be seriously affected).

In this sense, PQI's configuration is a key issue. For example, if voltage is always close to the +10 % or the −10 % setting, then swells or dips may be continuously triggering. Thus, it is important to run automatic batch processes for detecting excessive triggering and alerting for changing nominal values.

8.2.4 Data security

The PQMS should follow ISO/IEC information security related standards (such as IEC 62443 series) and the information security management requirements of the region or country. Technical measures such as data encryption, data backup, and anti-virus should be adopted to ensure the data security. It should have an access control function to allow only users with correct identity verification to access authorized resources and prevent unauthorized access to any resources.

8.3 Data setting

8.3.1 General

Some issues such as time aggregation method, harmonic and interharmonic measurement method are closely related to the monitoring purposes and may need to be adjusted. Therefore, these should be settable and should be customized by the system user according to the monitoring purpose.

8.3.2 Time aggregation setting

As mentioned earlier, for the purpose of performance analysis, generally 10 minute values are sufficient to obtain an accurate picture of the performance across a system. For the purpose of site characterization, it is recommended to use a shorter interval in order to obtain more detailed information depending on the nature of the customer's connection. Therefore, the aggregation time should be set according to different monitoring purposes.

8.3.3 Grouping and sub-grouping setting

According to IEC 61000-4-7, the grouping method should be adopted if only harmonics are evaluated. And the subgrouping method should be adopted if harmonics and interharmonics are evaluated separately (e.g. for the assessment of equipment prone to produce interharmonics). Moreover, for the purpose of troubleshooting or advanced applications and studies, raw unaggregated measurement data are most useful.

8.3.4 Flagged data pre-processing setting

As specified in IEC 61000-4-30, the flagged data should be excluded in the calculation of percentile values unless otherwise indicated. For example, for supply voltage deviation, data flagged by voltage dips and swells should be included in the calculation of percentile values. Therefore, the method to evaluate flagged data should be decided by the system user.

8.3.5 Sites attribution setting

The following attributes of monitoring sites should be defined by the user:

- Basic information, such as the name of the monitoring site, the location, voltage level, rated frequency, the ratio of VT or CT, the model, manufacturer, class of PQI, etc.
- Communication related parameters, such as communication mode, protocol, MAC address, IP address, etc.
- Data store related parameters, such as PQI storage capacity, aggregation time, etc.
- PQ parameter thresholds, such as voltage dip or swell threshold, harmonic limit, etc.

8.3.6 Time setting

Time accuracy is very important for PQM. The requirement of time-clock uncertainty accuracy specified by IEC 61000-4-30 can be achieved through a synchronization procedure applied periodically during a measurement campaign, through a GPS receiver, or through reception of transmitted radio timing signals or by using network timing signals. The time setting should be customized by the user according to the actual time synchronization method.

8.3.7 Accessing setting

System users should be managed hierarchically. All operators who log in to the system shall be authorized to perform identity and authority authentication, and use the specified system functions and operating ranges according to the authorized authority.

8.4 Power quality assessment

As mentioned in IEC TS 62749, generally, power quality assessments are made for network operator performance evaluation, troubleshooting and system planning. Methods for power quality assessment on the site and system aspects are defined in IEC TS 62749.

8.5 Advanced data analysis

The nature of the advanced data analysis is very much related to the aims of the measurement campaign or installation. The purpose of the analysis is to identify the behaviour of a particular set of PQ parameters as correlated to some other event(s). For example, what is the effect on a substation voltage level supplying a PV installation when the solar radiation changes.

Such analysis shall present results such that they can be readily interpreted and visualized by a variety of users. Whilst time-series graphs are useful, other plots can often reveal aspects of the data that are not obvious. For example, a plot of harmonic distortion level against time for a solar plant can be useful if the solar radiation is also plotted against time. However, a plot of distortion against PV power output can display any correlations more explicitly.

Presentation of results for many months of data can be a very difficult task and the effort required to analyse and visualize the data should not be underestimated. Having decided on an analysis approach, custom software, dedicated software provided by the PQ monitoring equipment manufacturer or third-party software can sometimes help automate the task.

It can also be useful to consider varying levels of time granularity when presenting results over long periods. This might be in the form of high-level summary plots to show the trends in parameters to help the user identify specific periods of interest, which can be examined in a higher level of detail as appropriate. For example, a high-level scoring system for extent of solar radiation coincident with the measurement can help the user identify period in the data to examine the effects of PV generation.

Event/exception reporting is commonly used in installations, such that the operator can ignore all the data until a pre-set threshold is exceeded and a warning is issued, although operators should guard against missing a trend showing the gradual build-up of a given PQ parameter and failing to plan mitigation until the acceptable threshold is exceeded.

Traditional statistical methods such as correlation are useful to quantify the link between PQ events and power system changes. For large data sets, data analytic techniques such as machine learning and data mining methods are also useful for detecting correlations between PQ event/exceptions and various power system interventions and changes. In some cases, techniques such as tipping point analysis can be used to anticipate and warn of a build-up of a particularly undesirable event such that operators can be pre-warned.

Interpretation of the results, drawing conclusions and making recommendations will also be required. This may include comparison to a baseline, for example how has a parameter changed due to some intervention in the network. Such comparisons would generally require a before and after study and would need to be identified at the planning stage.

The implications of the results for the network being studied will interest the network operator. Such interpretation will require information and possibly modelling and will need to be carried-out in collaboration with the network operator. In some cases, the results of the PQ study may be used to refine network models which may be in error due to a lack of historical information about the wiring configurations.

Annex A
(informative)

Characteristics of instrument transformers

A.1 Inductive instrument transformers

A.1.1 Inductive voltage transformers

Due to the resonance of the inductance of the winding and the stray capacitance between the winding layers, there are significant errors in the measurement of the amplitude and significant phase displacements for higher frequencies. The higher the system voltage, the higher is the effect. IEC TR 61869-103 gives the frequency response of a typical 420 kV inductive VT as shown in Figure A.1.

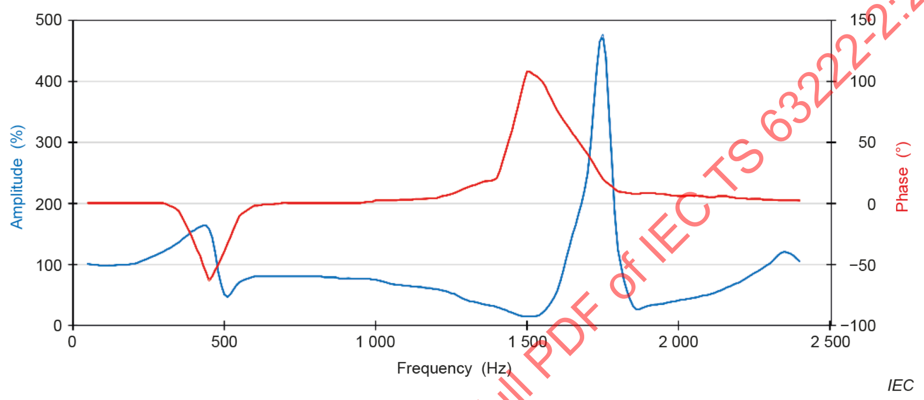

Figure A.1 – Frequency response of a typical 420 kV inductive VT

According to IEC TR 61869-103, the frequency range of inductive VT is as follows:

- LV voltage transformers

  Generally, LV voltage transformers are suitable for the harmonic up to 40th or 50th frequency range.

- MV voltage transformers

  If only amplitude accuracy is required, MV voltage transformers are generally suitable up to 1 kHz; if also phase angle accuracy is required, MV voltage transformers are suitable up to 700 Hz.

- HV voltage transformers

  HV voltage transformers are generally suitable only up to 500 Hz. Voltage transformers having rated primary voltage above 275 kV are not suitable for harmonic measurements above 250 Hz.

A.1.2 Inductive current transformers

Inductive CTs usually have a better behaviour with frequency than inductive VTs due to the lower capacitive error. The frequency range of inductive CT is as follows:

- LV current transformers

  Generally, LV current transformers are suitable for the harmonic up to 40^{th} or 50^{th} frequency range.

- MV current transformers

  All MV current transformers are suitable for measurements of amplitude in the harmonic range; in the case of phase angle measurements, the range is limited to about 1,5 kHz.

- HV current transformers

  The accuracy of HV current transformers is suitable for the measurement of 25th and below harmonics.