



BSI Standards Publication

Power quality management

Part 101: Power quality data application

National foreword

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TECHNICAL REPORT

**Power quality management -
Part 101: Power quality data application**



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**Power quality management -
Part 101: Power quality data application**

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8/1744/DTR	8/1750/RVDTR

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 Report is English.

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.

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.

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INTRODUCTION

With the development of modern industry, the integration of nonlinear loads, such as power-electronic-based equipment, electric locomotives, etc., causes direct or indirect power quality (PQ) issues.

The wide spread use of power quality monitoring instruments in recent years has accumulated massive PQ monitoring data hiding rich information for data applications in different fields. A typical case is the analysis of equipment operation condition, as many equipment failures present unique signatures in the voltage and current.

This technical report (TR) is prepared to support PQ management for PQ data application of system economical operation, potential risk early warning and consultation service. The mechanism and non-mechanism methodologies are introduced for various aspects of application scenarios including additional loss calculation, capacitor fault warning, harmonic source location, etc.,

PQ data application is based on the purposes and needs, the cases are limited in this document and cannot include all instances. The typical cases presented in this document are for fully understanding the application of power quality data.

1 Scope

This part of IEC 63222, which is a Technical Report, aims to provide guidelines for power quality data applications on different aspects in public power supply systems at voltage ranges from LV, MV and HV with 50 Hz or 60 Hz rated frequency.

It intends to provide a methodology for mining hidden knowledge and support power quality management based on PQ data analytics. Its primary goal is to serve different aspects of power system to promote the system maintaining its normal state and improve efficiency. It can also help avoid unexpected system events, equipment malfunction/maloperation, and production process interruption. The various methodologies and methods mentioned in this document are optional.

NOTE The boundaries between the various voltage levels can be different for different countries/regions. In the context of this document, the following terms for system voltage are used:

- low voltage (LV) refers to $U_N \leq 1 \text{ kV}$
- medium voltage (MV) refers to $1 \text{ kV} < U_N \leq 35 \text{ kV}$
- high voltage (HV) refers to $35 \text{ kV} < U_N \leq 230 \text{ kV}$

2 Normative references

There are no normative references in this document.

3 Terms and definitions

3.1 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>

3.1.1

electricity

set of the phenomena associated with electric charges and electric currents

[SOURCE: IEC 60050-121:1998, 121-11-76]

3.1.2

point of common coupling (PCC)

point in a public power supply network, electrically nearest to a particular load, at which other loads are or may be connected

[SOURCE: IEC 60050-617:2009, 617-01-05, modified – "electric current, voltage and frequencies" replaced by "electricity"]

3.1.3**power quality**

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

[SOURCE: IEC 60050-617:2009, 617-01-05, modified – "electric current, voltage and frequencies" replaced by "electricity"]

3.1.4**voltage deviation**

difference between supply voltage (U) and nominal voltage (U_N), often expressed by relative value

3.1.5**voltage dip**

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

Note 1 to entry: The starting threshold of voltage dip generally is 90 % of reference voltage.

[SOURCE: IEC 60050-161:1990, 161.08.10, modified – "from" replaced with "usually from", addition of Note 1 to entry.]

3.1.6**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]

3.1.7**harmonic frequency**

$f_{H,h}$

frequency which is an integer multiple of the power supply (fundamental) frequency

[SOURCE: IEC 61000-4-7:2002/AMD1:2008, 3.2.1]

3.1.8**Harmonic order**

h

integer ratio of a harmonic frequency ($f_{H,h}$) to the power supply frequency ($f_{H,1}$)

3.1.9**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 60050-161:1990, 161-08-09]

3.2 Abbreviated symbols

β	voltage deviation value
D	voltage unbalance degree
$\gamma_A, \gamma_B, \gamma_C$	current unbalance degree of phase A, phase B, and phase C
I_{A1}, I_{B1}, I_{C1}	the fundamental current of phase A, phase B, and phase C
I	the RMS value of current

I_h	the h-th harmonic current
U_h	the h-th harmonic voltage
$h_{\max}$	maximum harmonic order
$R_{t,h}$	the h-th harmonic resistance of a transformer
$R_{L,h}$	the h-th harmonic resistance of the line
$\tan\delta_h$	the h-th harmonic loss coefficient of the line (loss angle tangent value)

4 Understanding power quality data

4.1 General

Power quality indices are measured according to the methods defined in IEC 61000-4-30. Understanding the whole chain of measurement processing is critical for power quality data applications for different purposes.

Typically, raw unaggregated power quality measurement data are most useful for applications, as they permit any type of post-processing preferred.

The information in this clause is to help engineers in different areas to further understand PQ data for promoting PQ data application in expected areas.

4.2 For continuous power quality phenomenon

4.2.1 General

For continuous power quality phenomenon indices like voltage deviation, unbalance and harmonics (inter-harmonics), the basic record time duration is defined by IEC 61000-4-30 as 10 cycles for 50 Hz system and 12 cycles for 60 Hz system. The aggregation method is also defined as follows for getting the 150/180 cycle records and 10 min records respectively based on 10/12 cycle records.

$$X = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \dots + x_n^2)} \quad (1)$$

where $x_1, x_2, \dots, x_n$ are each of 10/12 cycle records included in 150/180 (or 3 s) cycles or 10 mins, n is the total record number, and X is the resultant aggregation record.

It is indicated that data stored in PQ measurement instrument or database is the RMS value of the corresponding variation signal during the specific time duration. The following cases try to illustrate the information issues relevant to PQ data.

For index of flicker, the basic record time duration is 10 min, the aggregation method below is used for getting the long term flicker (R_{lt}):

$$R_{lt} = \sqrt[3]{\frac{\sum_{i=1}^N P_{st,i}^3}{N}} \quad (2)$$

where $P_{st,i}$ ($i = 1, 2, 3, \dots$) are consecutive readings of the short-term severity P_{st} .

For index of frequency, the basic record time duration is 10 s, no aggregation method is defined.

4.2.2 Equivalent thermal effect but covering up the cause of possible overload

If 10 A current keeping for 1 s flows through a resistor with $1\ \Omega$ in 1 min, the aggregation method is used to get the final measurement result during a 1 min time duration. It will be 1,291 A.

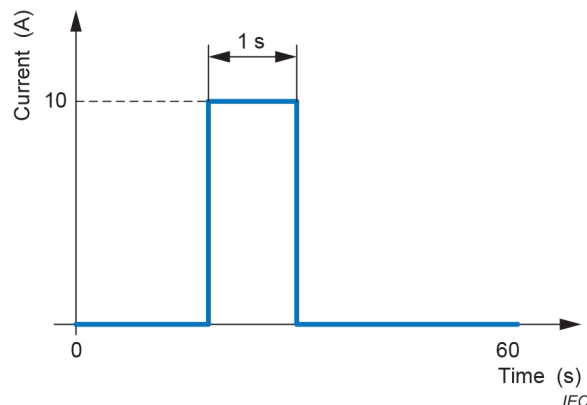


Figure 1 – Characteristics of original disturbance variation

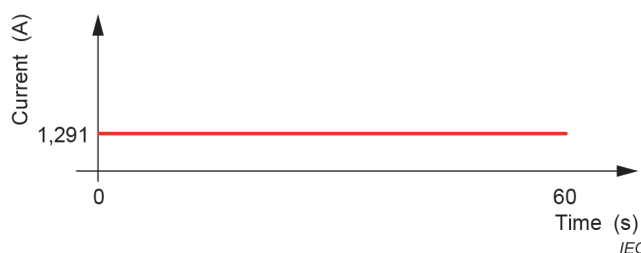


Figure 2 – Resultant aggregation data

Figure 1 and Figure 2 show different information of the disturbance. It is only equivalent to the thermal effect ($Q = 100\text{ J}$). If the resistor is damaged by the overcurrent of 10 A in 1 s, the resultant aggregation data of 1,291 A in 1 min loses the inrush current information. Therefore, for power-quality data applications, unaggregated data can be more useful.

4.2.3 Aggregation covering up the inducement for event of circuit tripping

Reference [35]¹ shows that for finding out the reasons for the event of circuit tripping, the measurement data measured according to IEC 61000-4-30 is useless, but the data measured in 1 cycle duration can be used for explaining the insight inducement. It is the harmonics keeping less than 1 cycle triggering this event, the aggregation result of 10 min data averages and immerses the short time rushing harmonics (Figure 3). The paper proposed that standards are created to provide an equal starting point for the power quality analysis and to help meters show the same values. However, in many cases limiting the information to standards prevented the troubleshooting engineer from monitoring the anomalies, not to mention identifying their sources.

¹ Numbers in square brackets refer to the Bibliography.

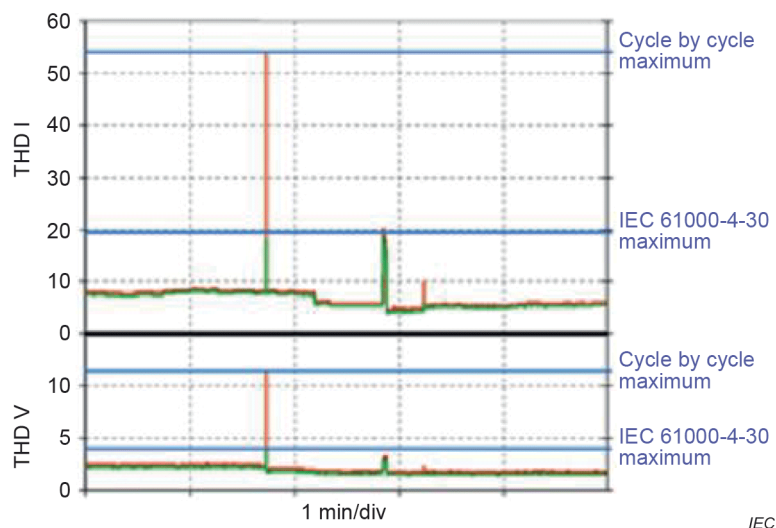


Figure 3 – Cycle-by-cycle and IEC 61000-4-30 aggregation THD

4.2.4 Comparison of different aggregation methods

Ten sets of data in a normal distribution with a standard deviation between 0,1 to 1 and an average value limited to around 4 are created. The aggregation methods like Maximum, Minimum, average, method defined by IEC 61000-4-30, and percentile are imposed on each set of data. The aggregation results are listed in Table 1.

It is illustrated that the results aggregated by IEC 61000-4-30 are very close to the average value and to the 50 % percentile value, showing that during almost 50 % times duration the disturbances are more serious than that reflected by the IEC 61000-4-30 aggregation result. It is also reminded that for power quality data applications, the focus can be paid to another 50 % times duration, and even different aggregation methods can be needed.

Table 1 – Comparison of different aggregation methods

Aggregation methods	1	2	3	4	5	6	7	8	9	10
Standard deviation	0,1102	0,2094	0,3042	0,3626	0,4661	0,6318	0,6780	0,8324	0,8683	1,0462
Min	3,6954	3,4468	3,2394	3,2329	2,8577	2,3240	2,5510	1,8140	1,7697	1,5389
Max	4,2810	4,5268	4,7443	5,0200	5,1880	5,8521	6,1268	5,8502	6,5328	6,2683
Average	4,0082	4,0339	3,9600	4,0156	4,0283	3,9725	4,0502	4,0659	3,9996	3,8286
IEC 61000-4-30	4,0097	4,0393	3,9716	4,0318	4,0549	4,0219	4,1060	4,1494	4,0919	3,9676
C50%	4,0108	4,0366	3,9353	4,0204	4,0467	3,9553	4,0780	4,0901	3,9715	3,7753
C95%	4,1959	4,4015	4,4751	4,5729	4,8009	4,9364	5,1349	5,6145	5,3161	5,6885
C99%	4,2573	4,5259	4,7194	4,9696	5,1474	5,5681	5,7674	5,7937	6,1646	6,1857

4.2.5 Impacts of sampling rules for aggregation

The data $X \in [\mu, \delta^2]$ (X_i is the i -th 10 cycle recorder) is created with normal distribution, e.g., $X: [3,5, 0,365^2]$ (total number is 432 000 in 1 day). For raw data obtained in different sampling rules below, same aggregation method defined by IEC 61000-4-30 is used, the resultant 95 % confidence intervals on the μ and δ are carried out, the results are listed in Table 2 and shown in Figure 4.

- In 150 cycles equally sampling 1 time 10 cycle recorder.

- In 150 cycles equally sampling 3 times 10 cycle recorders.
- In 150 cycles equally sampling 5 times 10 cycle recorders.
- In 150 cycles equally sampling 15 times 10 cycle recorders (as defined by IEC 61000-4-30).

Table 2 – Aggregation results for different sampling rules

Confidence intervals	Sampling rule				
	X	1 time sampling	3 times sampling	5 times sampling	15 times sampling
Average	3,5	3,496 766	3,512 729	3,513 632	3,517 614
Standard deviation	0,364 137	0,361 993	0,209 539	0,162 014	0,0 948
95 % confidence intervals for average range	3,498 914	3,492 585	3,510 309	3,511 761	3,516 519
	3,501 086	3,500 947	3,51 515	3,515 503	3,518 709
95 % confidence intervals for standard deviation range	0,363 371	0,359 061	0,207 842	0,160 702	0,094 032
	0,364 907	0,364 973	0,211 265	0,163 349	0,09 558
95 %	4,098 505	4,090 555	3,860 124	3,783 118	3,672 845
Max	5,116 398	4,922 223	4,455 225	4,274 328	3,904 971

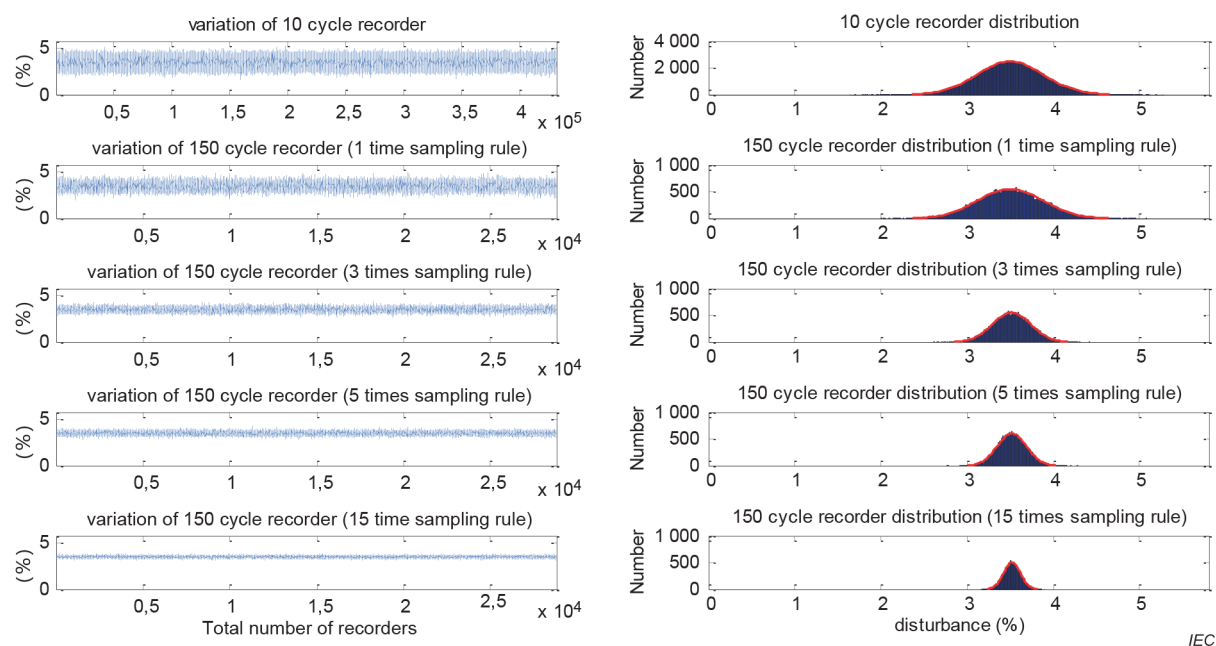
**Figure 4 – Resultant aggregation data for different sampling rules**

Figure 4 and Table 2 illustrate that:

- For different sampling rules, the distribution of the resultant aggregation data is also normal distribution with an almost unchanged average value.
- With the increase of the sampling times, the standard deviation of the resultant aggregation data drops rapidly, the distribution tends to be concentrated, and the 95 % percentile value and the maximum value are also reduced.
- 1 time sampling almost does not change the data distribution, likely no aggregation method is applied.

4.3 For discontinuous PQ phenomenon

4.3.1 General

For discontinuous PQ phenomena like voltage dip, swell and short-time interruption, the characteristics are defined by residual voltage and duration measured according to IEC 61000-4-30. It is also mentioned that the uncertainty of a dip or swell time duration is equal to 1 cycle for class A or 1 or 2 cycles for class S. Like continuous PQ phenomena, the aggregation methods for events can also be applied.

4.3.2 Detailed event description

Residual voltage and time duration rely on the defined threshold. For an event like Figure 5, there are many sets of residual voltage with corresponding time duration according to defined thresholds. The only one set cannot describe the event in detail. A detailed curve of RMS variation might be needed for post analysis; even the point-on-wave curve is needed for deeply analysing the event insight.

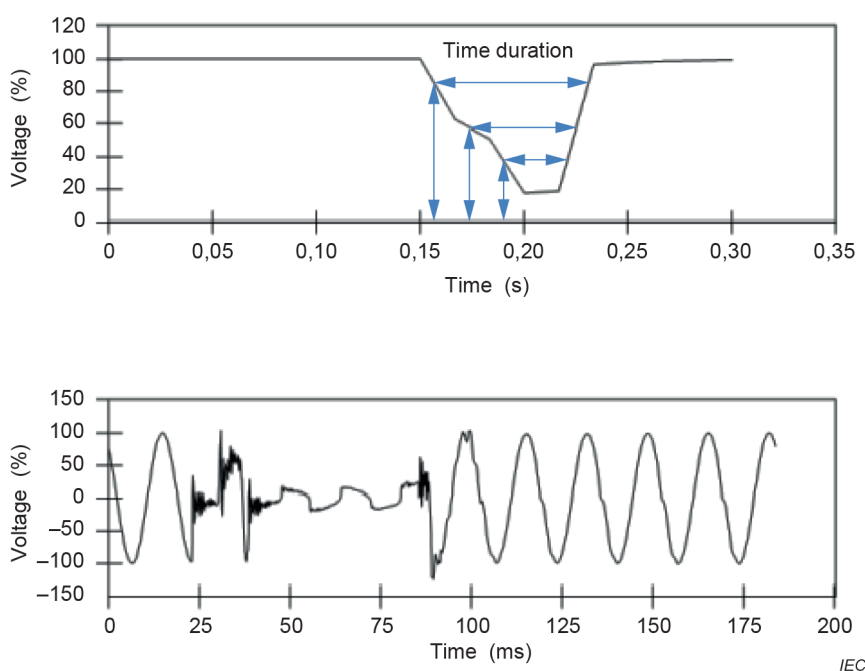


Figure 5 – An example showing information of a single event

4.3.3 Aggregation for event

As mentioned in Annex B of IEC TS 62749:2020, different aggregation methods can be applied for event assessment, the rules of how the events to be aggregated depend on the specific purposes for a particular assessment. The resultant aggregation data can be more roughly used for specific area data applications.

4.3.4 Critical current information with corresponding event

For PQ data application, voltage disturbance combining the corresponding current variation (e.g., Figure 6) might be more useful. The information of current is invaluable in determining sources/causes of power quality disturbances, e.g., it can help to determine if the cause of the problem is up stream or downstream of the measuring instrument.

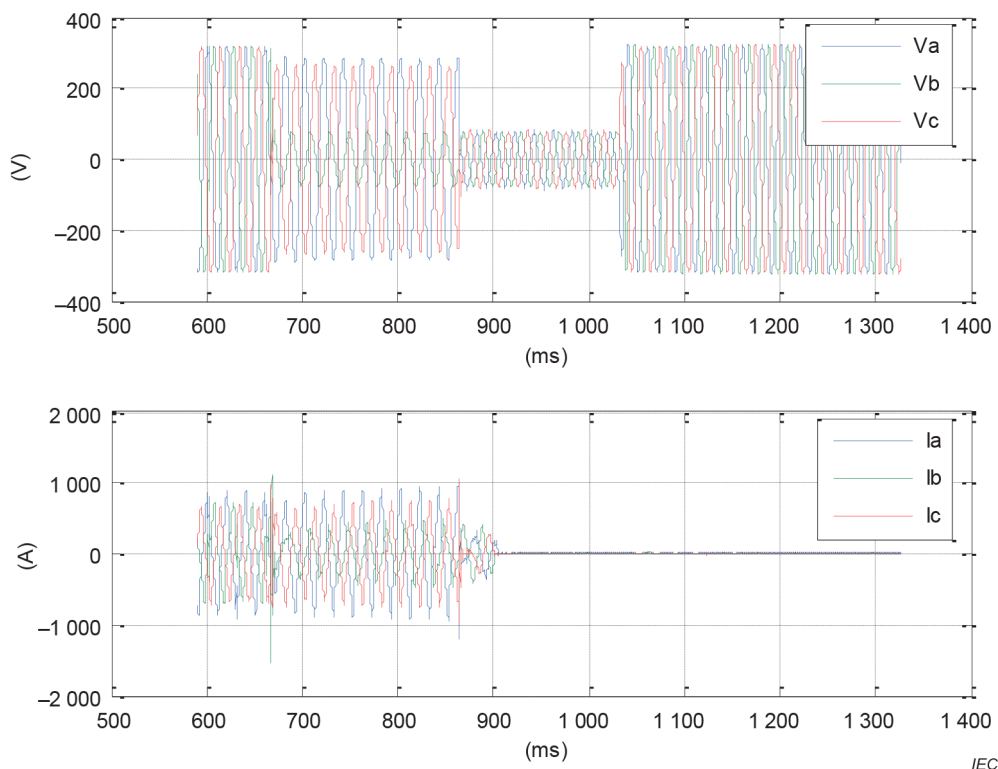


Figure 6 – Point on wave of the event with the corresponding current

5 Methodology for power quality data application

5.1 General

Some preliminary work might be needed before the application of power quality data. In this clause, the algorithms for missing power quality data filling and abnormal power quality data identification are introduced. Meanwhile, the mechanism method and non-mechanism method are also introduced.

5.2 Data pre-processing

5.2.1 General

Data cleaning is the first step of power quality data pre-processing. Data cleaning guarantees the consistency, correctness, completeness of power quality data, so that to achieve the effective development of power quality data application. The main concerns of power quality data cleaning are missing data filling, and abnormal data identification.

5.2.2 Missing power quality data filling

5.2.2.1 Basic principles

Power quality data missing can occur due to the failure and maintenance of CTs/PTs and monitoring equipment, or partial data loss due to interference in the channel during the propagation of the communication channel (e.g., power line carrier). The missing of power quality data will lead to deviations in data analysis, and the analysis result will not reflect the realistic system operation, affecting the decision-making as well. Power quality data has intrinsic characteristics such as temporal characteristics and data autocorrelation; these intrinsic characteristics are an important basis for missing data filling.

The general flowchart of missing data inferred by the available data is shown in Figure 7.

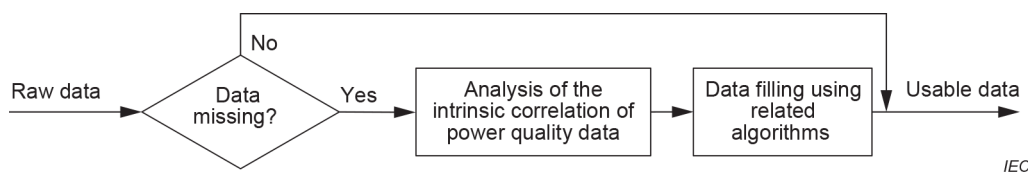


Figure 7 – Flowchart of missing power quality data filling

5.2.2.2 Related algorithms

5.2.2.2.1 Regression analysis-based method

The process of the regression analysis-based method is as follows:

- To calculate the correlation coefficients between the index to be filled and different power quality indices, find out strong correlated indices.
- Regression method will be used based on the monitoring dataset for establishing the regression prediction model.
- Use the prediction model to get the missing data.

5.2.2.2.2 Mean value-based method

In case of short-time data missing, the mean value-based method can be used. This simple method uses the information from the existing data to infer the missing value. The weighted mean value method is also recommended in this document.

5.2.3 Abnormal power quality data identification

5.2.3.1 Basic principles

Abnormal power quality data can be caused by hardware failure of PQ monitoring equipment, monitoring environment worsening, parameter configuration errors, and manual misoperation.

The purpose of abnormal power quality data identification is to avoid a misleading decision-making process. The general flowchart of abnormal power quality data identification is shown in Figure 8.



Figure 8 – Flowchart of abnormal power quality data identification

5.2.3.2 Related algorithms

5.2.3.2.1 Correlation-based method

The process of the correlation-based method is as follows:

- To calculate the correlation coefficients between the index to be identified and different power quality indices, find out the strongest correlated index.
- Use raw data of index to be identified and the selected correlated index to establish a regression model.
- Use the established regression model to get the regression values, which are compared with the corresponding monitoring data for estimating error.

Threshold is set for identifying the abnormal data.

5.2.3.2.2 Time series-based method

The process of the time series-based method is as follows:

- a) Obtain the time series data set of the index to be identified.
- b) Get the time series model by the aforementioned data set.
- c) Use the time series model to predict the entire time series data set, calculate the relative error set between the predicted data and the raw data.
- d) Threshold is set for identifying the abnormal data.

5.2.3.2.3 Wavelet-based method

The process of the wavelet-based method is as follows:

- a) Create an abnormal waveforms database based on the possible scenarios that might occur.
- b) Use wavelet-based method on the abnormal waveform to form a library of resultant coefficients.
- c) Use a wavelet-based method on the data set to be identified to get the corresponding resultant coefficients.
- d) Threshold is set for identifying the abnormal data by comparing two sets of the resultant coefficient.

5.3 Mechanism method

The mechanism method is based on the mechanism model. The mechanism model is obtained by listing various balance equations according to theories of physics and electricity, which has clear physical meaning.

5.4 Non-mechanism method

The non-mechanism method is based on the non-mechanism model. The non-mechanism model is also called the I/O Model. In the non-mechanism model, the input variables are the power quality data and the output variables are the corresponding results of the power quality data application scenarios. Internal physical processes are uncertain. In cases where the mechanical model cannot be constructed properly, non-mechanism method might be needed.

6 Application on system economical operation

6.1 General

According to IEC TR 63222-100, power quality phenomena can result in additional loss of equipment and power system. Additional loss can be calculated based on power quality data, which contributes to power grid economic operation analysis.

6.2 Approach

6.2.1 Analysis of additional loss of transformer

6.2.1.1 Mechanism method

The additional loss of the transformer is:

$$\Delta P_T = \Delta P_{T_deviation} + \Delta P_{T_unbalance} + \Delta P_{T_harmonic} \quad (3)$$

Where: $\Delta P_{T_deviation}$ is the additional loss of transformer caused by voltage deviation, $\Delta P_{T_unbalance}$ is the additional loss of transformer caused by voltage unbalance, $\Delta P_{T_harmonic}$ is the additional loss of transformer caused by harmonic current/voltage.

a) The additional loss of transformer caused by voltage unbalance is:

$$\Delta P_{T_unbalance} = f(D, U) \quad (4)$$

Where: D is the voltage unbalance degree. The formula corresponding to a specific transformer is to be provided by the relevant manufacturer.

b) The additional loss of transformer caused by voltage deviation is:

$$\Delta P_{T_deviation} = \Delta P_{Fe} + \Delta P_{Cu} \quad (5)$$

Where: ΔP_{Fe} is the additional loss of transformer iron loss caused by voltage deviation, ΔP_{Cu} is the additional copper loss caused by the voltage deviation.

1) The additional loss of transformer iron loss caused by voltage deviation is:

$$\Delta P_{Fe} = (\beta^2 + 2\beta) \left(\frac{U_N}{U_{TN}} \right)^2 P_0 \quad (6)$$

Where: β is the voltage deviation value, U_{TN} is the rated voltage of the transformer secondary side, P_0 is the rated iron loss of the transformer, ΔP_{Fe} is the actual iron loss of the transformer.

2) The additional copper loss caused by the voltage deviation is:

i) When the access load type in the system is constant power load:

$$\Delta P_{Cu} = - \frac{(\beta^2 + 2\beta) S_N^2 L^2}{(\beta + 1)^2 U_N^2} R_C \quad (7)$$

Where: β is the voltage deviation value, S_N is the rated capacity of the transformer, U_N is the rated voltage of the transformer's secondary side, I_N is the rated current of the transformer's secondary side, L is the load rate, R_C is the line resistance or the total resistance of the primary and secondary voltage windings of the transformer, ΔP_{Fe} is the copper loss.

Where L is the load rate:

$$L = \frac{\sqrt{P^2 + Q^2}}{S_N} \times 100\% \quad (8)$$

Where: P is the equivalent load active power at the end of the line, Q is the equivalent load reactive power at the end of the line.