



TECHNICAL REPORT

Instrument transformers – The use of instrument transformers for power quality measurement

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **XC**

ICS 17.220.20

ISBN 978-2-88912-073-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD	6
1 Scope	8
2 Normative references	8
3 Terms and definitions	9
4 Nature of the problem	12
5 Power quality parameters according to IEC 61000-4-30:2008	13
5.1 General	13
5.2 Power quality measurement chain	13
5.3 Signal processing according to IEC 61000-4-30:2008	14
5.4 Power frequency	15
5.5 Magnitude of the supply voltage	15
5.6 Flicker	15
5.7 Supply voltage dips and swells	17
5.8 Voltage interruptions	18
5.9 Transient voltages	19
5.10 Supply voltage unbalance	19
5.11 Voltage harmonics	20
5.12 Voltage inter-harmonics	21
5.13 Mains Signalling Voltages on the supply voltage	21
5.14 Rapid voltage changes	21
5.15 Measurement of underdeviation and overdeviation parameters	21
5.16 Summary of the requirements placed by the measure of power quality parameters	21
6 Impact of instrument transformers on PQ measurement	22
6.1 General	22
6.2 Inductive instrument transformers	24
6.2.1 Inductive voltage transformers	25
6.2.2 Inductive CTs	30
6.3 Capacitive voltage transformers (CVTs)	35
6.3.1 Standard application	35
6.3.2 Special measurement techniques	39
6.4 Electronic instrument transformers	42
6.4.1 General	42
6.4.2 Common accuracy classes	42
6.4.3 Electronic VTs	43
6.4.4 Electronic CTs	55
7 Tests for power quality	67
7.1 Test procedure for VT frequency response	68
7.2 Test set-up for VT frequency response test	68
7.3 Test procedure for CT frequency response	70
7.4 Test set-up for CT frequency response test	70
7.5 Special considerations for test of electronic instrument transformers with digital output	72
7.6 Tests for electronic instrument transformers according to IEC Standard 60044-8	72
7.6.1 Test arrangement and test circuit	73

Annex A Instrument transformers and power quality measurement – open issues	75
Annex B Transformer classes	79
Bibliography.....	81
Figure 1 – Measurement chain (From [8], modified)	14
Figure 2 – Contribution of instrument transformers in overall measurement uncertainty (from [9], modified)	14
Figure 3 – Example of voltage fluctuation causing flicker	16
Figure 4 – Demodulation within the IEC flickermeter	17
Figure 5 – Example of voltage dip (courtesy of Italian distribution network monitoring system – QuEEN)	18
Figure 6 – Example of voltage interruption (courtesy of Italian distribution network monitoring system – QuEEN)	19
Figure 7 – Example of voltage unbalance (courtesy of Italian distribution network monitoring system- QuEEN).....	20
Figure 8 – Example of voltage harmonics.....	21
Figure 9 – Voltage transformer technologies frequency range according to present experience	23
Figure 10 – Current transformer technologies frequency range according to present experience	24
Figure 11 – Example of equivalent circuit for an inductive voltage/current transformer	25
Figure 12 – Cross-section view of an inductive voltage transformer for voltages over 1 kV and up to 52 kV (courtesy of Schneider Electric).....	26
Figure 13 – Cross-section view of a freestanding High Voltage VT (courtesy of Trench Switzerland AG).....	28
Figure 14 – Frequency response of a typical inductive VT 420 kV (courtesy of Trench Switzerland AG).....	29
Figure 15 – First resonance peak depending on the system voltage U_m (courtesy of Trench Switzerland AG)	29
Figure 16 – Cross-section view of a current transformer (courtesy of Schneider Electric)	32
Figure 17 – Results obtained for a 245 kV CT (courtesy of Trench Switzerland AG).....	34
Figure 18 – Results obtained for a 245 kV CT: detail (courtesy of Trench Switzerland AG) ...	34
Figure 19 – Cross-section view of a capacitive voltage transformer (Courtesy of Trench Switzerland AG).....	35
Figure 20 – CVT: Equivalent circuit at power frequency	36
Figure 21 – Simplified CVT Thevenin equivalent circuit at power frequency without compensating reactor	37
Figure 22 – Simplified CVT Thevenin equivalent circuit at power frequency	37
Figure 23 – Complete CVT Thevenin equivalent circuit at power frequency.....	38
Figure 24 – Measurements performed by means of a CVT with harmonic measurement terminal	40
Figure 25 – Comparison of different measurements with and without harmonic monitoring terminal (Courtesy of Trench Switzerland AG, based on [16])	41
Figure 26 – Basic design for a bulk crystal producing a Pockels Effect (courtesy of Alstom Grid)	45
Figure 27 – Various solutions to apply voltage on the active crystal	46
Figure 28 – Various methods to divide the full voltage before applying on the crystal.....	46

Figure 29 – Basic design for a Pockels sensor (courtesy of Alstom Grid)	47
Figure 30 – Industrial bulk Pockels Cell (courtesy of Alstom Grid).....	47
Figure 31 – Frequency response calculation for an optical VT (courtesy of Alstom Grid)	48
Figure 32 – Cross-section view and electrical scheme of a resistive voltage divider (from [22]).....	49
Figure 33 – Ratio error of an MV resistive divider (courtesy of Trench Switzerland AG)	50
Figure 34 – Phase error of MV resistive divider (courtesy of Trench Switzerland AG).....	50
Figure 35 – Electrical scheme of a capacitive voltage divider	51
Figure 36 – Equivalent circuit of an RC voltage divider (from [23], [24])	53
Figure 37 – Equivalent circuit of a balanced RC voltage divider (from [24])	53
Figure 38 – Frequency response of an RC voltage divider (courtesy of Trench Switzerland AG).....	54
Figure 39 – Measurements done on an RC voltage divider with a voltage level of 145 kV with a cable length of 150 m (courtesy of Trench Switzerland AG)	54
Figure 40 – Principle of optical CT measurement (from [22]).....	56
Figure 41 – Principle of optical CT measurement (Courtesy of Alstom Grid).....	56
Figure 42 – Frequency response calculation for an optical CT (Courtesy of Alstom Grid)	57
Figure 43 – Typical frequency response measurement of a LPCT (Courtesy of Trench Switzerland AG).....	58
Figure 44 – Equivalent circuit for a Rogowski coils (Courtesy of Alstom Grid))	59
Figure 45 – Electrical scheme and picture of a Rogowski current transformer (Courtesy of Alstom Grid).....	61
Figure 46 – Electrical scheme of a shunt current measurement (Courtesy of Alstom Grid)	62
Figure 47 – Shunt for DC application (Courtesy of Alstom Grid)	63
Figure 48 – Equivalent circuit for a compensated shunt	63
Figure 49 – Theoretic possible bandwidth of a shunt 5 kA /150 mV (Courtesy of Alstom Grid)	64
Figure 50 – Hall Effect Sensor	65
Figure 51 – Hall Effect Sensor (Courtesy of Schneider Electric – From [38])	66
Figure 52 – Hall Effect Sensor (Courtesy of Schneider Electric – From [38])	66
Figure 53 – Test circuit for VT frequency response test	69
Figure 54 – Test circuit for VT frequency response test	70
Figure 55 – Test circuit for CT frequency response test	71
Figure 56 – Test circuit for CT frequency response test	72
Figure 57 – Test set-up for electronic instrument current transformers with digital output	73
Figure 58 – Test set-up for electronic current transformers with analogue output	74
Figure A.1 – Examples of “fake dips”, transients recorded at the secondary winding of MV voltage transformers due to voltage transformers saturation (courtesy of Italian distribution network monitoring system- QuEEN).....	78
Table 1 – Power quality disturbances and measurement interval as per IEC 61000-4- 30:2008	15
Table 2 – Transformer parameters influencing power quality measurement.....	22

Table 3 – Main components of an inductive voltage transformer for voltages over 1 kV and up to 52 kV	26
Table 4 – Inductive voltage transformers for voltages over 1 kV and up to 52 kV: impact on the measurements of PQ Parameters	27
Table 5 – Inductive voltage transformers for voltages over 52 kV and up to 1 100 kV: impact on the measurements of PQ parameters	30
Table 6 – Main components of an inductive current transformer for voltages over 1 kV up to 52 kV	31
Table 7 – Inductive CTs for voltages over 1 kV up to 52 kV: impact on the measurements of PQ parameters	32
Table 8 – Main components of an inductive current transformer for voltages above 52 kV up to 1 100 kV	33
Table 9 – Inductive CTs for voltages over 52 kV up to 1 100 kV: impact on the measurements of PQ parameters	35
Table 10 – Capacitive voltage transformers: impact on the measurements of PQ parameters	39
Table 11 – Capacitive voltage transformer with harmonic measurement terminal: impact on the measurements of PQ parameters	41
Table 12 – Capacitive voltage transformer with additional equipment for PQ measurement: impact on the measurements of PQ parameters	42
Table 13 – Accuracy classes for power metering	43
Table 14 – Accuracy classes for power quality metering	43
Table 15 – Optical voltage transformer: impact on the measurements of PQ parameters	48
Table 16 – MV resistive divider: impact on the measurements of PQ parameters	51
Table 17 – Capacitive voltage dividers: impact on the measurements of PQ parameters	52
Table 18 – RC voltage divider: impact on the measurements of PQ parameters	55
Table 19 – Optical current transformer: Impact on the measurements of PQ parameters	57
Table 20 – Main components of LPCTs	58
Table 21 – Main components of Rogowski sensors	61
Table 22 – Rogowski current transformer: Impact on the measurements of PQ parameters	62
Table 23 – Shunt: Impact on the measurements of PQ parameters	64
Table 24 – Hall effect sensor: Impact on the measurements of PQ parameters	67
Table 25 – Power quality parameters and requirements for CT and VT	68
Table 26 – Test currents and voltages for the common accuracy classes	72
Table 27 – Test currents and voltages for special accuracy classes	72
Table B.1 – Example of test table with possible main requirements for accuracy tests	80

INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSTRUMENT TRANSFORMERS – THE USE OF INSTRUMENT TRANSFORMERS FOR POWER QUALITY MEASUREMENT

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61869-103, which is a technical report, has been prepared by IEC technical committee 38: Instrument transformers.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
38/402/DTR	38/409/RVC

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

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

A list of all the parts in the IEC 61869 series, published under the general title *Instrument transformers*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The ‘colour inside’ logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INSTRUMENT TRANSFORMERS – THE USE OF INSTRUMENT TRANSFORMERS FOR POWER QUALITY MEASUREMENT

1 Scope

This part of IEC 61869 is applicable to inductive and electronic instrument transformers with analogue or digital output for use with electrical measuring instruments for measurement and interpretation of results for power quality parameters in 50/60 Hz a.c. power supply systems.

This part of IEC 61869 aims at giving guidance in the usage of HV instrument transformers for measuring power quality parameters.

The power quality parameters considered in this document are power frequency, magnitude of the supply voltage and current, flicker, supply voltage dips and swells, voltage interruptions, transient voltages, supply voltage unbalance, voltage and current harmonics and interharmonics, mains signalling on the supply voltage and rapid voltage changes.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60044-8:2002, *Instrument transformers – Part 8: Instrument transformers: Electronic current transformers*

IEC 61000-2-1:1990, *Electromagnetic compatibility (EMC) – Part 2-1: Environment – Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*

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

IEC 61000-4-7:2002, *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 61000-4-15:2010, *Electromagnetic compatibility (EMC) – Part 4-15: Testing and measuring techniques – Flickermeter – Functional and design specifications*

IEC 61000-4-30:2008, *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods*

IEC 60359:2001, *Electrical and electronic measurement equipment – Expression of performance*

IEC 61557-12:2007, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 12: Performance measuring and monitoring devices (PMD)*

EN 50160:2007, *Voltage characteristics of electricity supplied by public distribution networks*