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Date: 06 December 2023

Origin: International

Latest date for receipt of comments: 24 January 2024

Project No. 2023/02919

Responsible committee: PEL/14 Power transformers

Interested committees:

Title: BS EN IEC 60076-6 Power transformers

Part 6: Reactors

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER:

IEC 60076-6 ED2

DATE OF CIRCULATION:

2023-12-01

CLOSING DATE FOR COMMENTS:

2024-02-23

SUPERSEDES DOCUMENTS:

14/1111/RR

IEC TC 14 : POWER TRANSFORMERS

SECRETARIAT:

United Kingdom

SECRETARY:

Ms Stephanie Lavy

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 33, TC 38

PROPOSED HORIZONTAL STANDARD:



Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

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TITLE:

Power transformers - Part 6: Reactors

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 6: Reactors

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International Standard IEC 60076-6 has been prepared by IEC technical committee 14: Power Transformers

IEC 60076-6 Edition 1 cancels and replaces IEC 60289 Edition 2 published in 1988.

The text of this standard is based on the following documents:

FDIS	Report on voting
XX/XX/FDIS	XX/XX/RVD

Full information on the voting for the approval of this standard 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.

81 The committee has decided that the contents of this publication will remain unchanged until the
82 maintenance result date¹⁾ indicated on the IEC web site under "<http://webstore.iec.ch>" in the
83 data related to the specific publication. At this date, the publication will be

- 84 • reconfirmed,
- 85 • withdrawn,
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INTRODUCTION

This part of IEC 60076 is intended to provide the basis for the specification and testing of the types of reactors given in the scope. The document also gives some important information on certain reactor applications to aid the preparation of a reactor specification.

Wherever possible, references to technical clauses in the other parts of IEC 60076 which are relevant to power transformers have been made. However, because reactors have some fundamental differences to transformers there are special considerations that apply to the specification, testing and application of reactors. These are included in this document.

Clauses 1 to 6 form the general parts of the document, which apply to all types of reactor. Clauses 7 to 13 deal individually with each different type of reactor. Generally, only one of the clauses 7 to 13 will apply to a specific reactor.

This standard has more than one definition section. The general definitions given in clause 3 apply to the whole document. Each of the clauses 7 to 13 dealing with a certain type of reactor includes a definition section relevant and applying only to that clause.

Clauses 7 to 13 follow a uniform structure. Within this structure, the Rating section sets out the minimum information that a purchaser must supply with the reactor specification. The test section in each clause defines the relevant tests that can be applied to that particular type of reactor and may include some additional items that must be agreed at the time of order.

Annexes A, B, C, D, F and G provide further information for certain reactor applications and testing. Annex E (normative) describes the dielectric turn-to-turn test. Annex H gives guidelines for the specification of Shunt and Current limiting reactors.

This standard covers both dry-type and liquid-immersed reactors and where clauses or sections apply to only one type this is made clear.

Where possible the requirements of this document have been harmonised with the equivalent IEEE standard.

POWER TRANSFORMERS –

Part 6: Reactors

1 Scope

This standard applies to the following types of reactors:

- shunt reactors.
- series reactors including current-limiting reactors, neutral-earthing reactors, power flow control reactors, motor starting reactors, arc-furnace series reactors.
- filter (tuning) reactors.
- capacitor damping reactors.
- capacitor discharge reactors.
- earthing transformers (neutral couplers).
- arc-suppression reactors.
- smoothing reactors for HVDC and industrial applications.
- converter reactors for VSC HVDC multilevel converters.

with the exception of the following reactors:

- reactors with a rating less than 1 kvar single-phase and 5 kvar three-phase.
- reactors for special purposes such as high-frequency line traps or reactors mounted on rolling stock.

Where IEC standards do not exist for small or special reactors, this standard may be applicable as a whole or in part.

For variable reactors there is a possibility to change the reactance by biasing the core with a DC current. This principle can be used for Shunt reactors (MCSR Magnetically Controllable Shunt Reactors) and for series reactors. The reactors are built on special transformer cores with extra windings differently wound around the legs of the core(s). One main winding, one for biasing the core and in some cases control windings.

More information can be found in the Cigre brochure 655 and in different publications.

Most of the tests described in this standard are also suitable on these reactors. The details of the tests are not described in this standard and has to be discussed between purchaser and supplier on these special reactors.

2 Normative references

The following referenced documents are indispensable for the application 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 60076-1:2011, *Power transformers – Part 1: General*

IEC 60076-2:2011, *Power transformers – Part 2: Temperature rise*

IEC 60076-3:2013, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

- 162 IEC 60076-4:2002, *Power transformers – Part 4: Guide to lightning impulse and switching*
163 *impulse testing – Power transformers and reactors*
- 164 IEC 60076-5:2006, *Power transformers – Part 5: Ability to withstand short-circuit*
- 165 IEC 60076-7:2005, *Power transformers – Part 7: Loading guide for oil-immersed power*
166 *transformers*
- 167 IEC 60076-8:1997, *Power transformers – Part 8: Application guide*
- 168 IEC 60076-10:2016, *Power transformers – Part 10: Determination of sound levels*
- 169 IEC 60076-10-1:2016, *Power transformers – Part 10: Determination of sound levels –*
170 *Application guide*
- 171 IEC 60076-11:2018, *Power transformers – Part 11: Dry-type transformers*
- 172 IEC 60076-12:2008, *Loading guide for dry-type power transformers*
- 173 IEC 60076-25:2023, *Power transformers – Part 25: Neutral grounding resistors*
- 174 IEC/IEEE 60076-57-129:2017, *Power transformers – Part 57-129: Transformers for HVDC*
175 *applications*
- 176 IEC 60060-1:2010, *High-Voltage test techniques – Part 1: General definitions and test*
177 *requirements*
- 178 IEC 60137:2017, *Insulated bushings for alternating voltages above 1000 V*
- 179 IEC 60143:2015, *Series capacitors for power systems*
- 180 IEC 60168:1994+A1:1997+A2:2000, *Tests on indoor and outdoor post insulators of ceramic*
181 *material or glass for systems with nominal voltages greater than 1000 V*
- 182 IEC/IEEE 60214-2:2019, *Tap-changers – Part 2: Application guidelines*
- 183 IEC 60270:2000+A1:2015, *High-voltage test techniques – Partial discharge measurements*
- 184 IEC 60273:1990, *Characteristic of indoor and outdoor post insulators for systems with nominal*
185 *voltages greater than 1000 V*
- 186 IEC 60721-2-6:1990, *Classification of environmental conditions – Part 2: Environmental*
187 *conditions appearing in nature. Earthquake vibration and shock*
- 188 IEC 60815-(all parts):2008, *Selection and dimensioning of high-voltage insulators intended for*
189 *use in polluted conditions*
- 190 IEC 60871-1:2014, *Shunt capacitors for a.c. power systems having a rated voltage above*
191 *1000V*
- 192 IEC/TR 60943:1998+A1:2009, *Guidance concerning the permissible temperature rise for parts*
193 *of electrical equipment, in particular for terminals*
- 194 IEC 61378-1:2011, *Converter transformers – Part 1: Transformers for industrial applications*

195 IEC 62271-110:2017, *High-voltage switchgear and controlgear – Part 110: Inductive load*
196 *switching*

197 **3 Definitions**

198 The definitions given in this clause are of a general nature. Additional definitions are given in
199 those clauses of the standard which are specific to a particular type of reactor or which are
200 given a particular meaning when related to that type of reactor.

201 There are frequent references to technical clauses in IEC 60076 concerning transformers and
202 transformer testing. The terminology of those standards may not always be strictly relevant in
203 the context of reactors. For example “induced AC withstand voltage test” is a test on a reactor
204 where there is a test voltage across the winding although it is not “induced” from another
205 winding, but applied directly from the test source.

206 **3.1 Types of reactor**

207 **3.1.1**

208 **shunt reactor**

209 a reactor connected phase-to-earth, phase-to-neutral or between phases in a power system to
210 compensate for capacitive current

211 **3.1.2**

212 **current-limiting reactor**

213 a reactor connected in series in a power system to limit the current under system fault conditions

214 **3.1.3**

215 **converter reactor**

216 a reactor connected in series in the converter of a voltage sourced converter (VSC) HVDC
217 scheme to provide di/dt limitation, short circuit protection and limitation of the rate-of-rise of s/c
218 current as well as to improve controllability of the converter and controllability of the
219 power/reactive power exchange in a VSC HVDC system. These reactors are installed in the
220 arms of the converter and can be placed at the DC side after the valve having full d.c. voltage
221 to ground or on the ac side prior the valve having full AC voltage to ground. For bi-polar or
222 asymmetric scheme topographies, the AC side reactors are on half of the d.c. potential to
223 ground.
224

225 **3.1.4**

226 **neutral-earthing reactor**

227 a reactor connected between the neutral of a power system and earth to limit the line-to-earth
228 current under system earth fault conditions to a desired value

229 **3.1.5**

230 **power flow control reactor**

231 a reactor connected in series in a power system to control the power flow

232 **3.1.6**

233 **motor starting reactor**

234 a reactor connected in series with a motor to limit the inrush current during the motor starting
235 operation

236 **3.1.7**

237 **arc-furnace series reactor**

238 a reactor connected in series with an arc-furnace to increase the efficiency of the metal melting
239 operation and reduce voltage variation on the power system

3.1.8**damping reactor**

a reactor connected in series with shunt capacitors to limit the inrush current when the capacitor is energised, limit the outrush current during close-in faults or adjacent capacitor switching and/or to detune capacitor banks in order to avoid resonance with the power system

3.1.9**filter reactor**

a reactor connected in series or in parallel with capacitors to reduce or block harmonics or control signals (ripple signals) with frequencies up to 10 kHz

3.1.10**discharge reactor**

a reactor used in the bypass/discharge circuit of high voltage power system series capacitor bank applications to limit the current under fault conditions

3.1.11**earthing transformer (neutral coupler)**

a three-phase transformer or reactor connected in a power system to provide a neutral connection for earthing either directly or via an impedance

NOTE Earthing transformers may in addition supply a local auxiliary load.

3.1.12**arc-suppression reactor**

a reactor connected between the neutral of a power system and earth to compensate for the capacitive line-to-earth current due to a single-phase earth-fault (resonant-earthed system)

3.1.13**smoothing reactor**

a reactor connected in series in a d.c. system to reduce the flow of alternating currents and transient overcurrent

3.2 Other definitions**3.2.1****dry-type reactor**

a reactor in which the coils are neither impregnated with an insulating liquid nor immersed in an insulating liquid. The insulating medium for the windings is a solid dielectric and/or air. The insulation to ground is provided by porcelain or polymeric insulators.

3.2.2**liquid-immersed reactor**

A shunt reactor in which the coils and magnetic circuit are immersed in or impregnated with an insulating oil or liquid.

3.2.3**highest voltage for equipment U_m**

the basis for the insulation level of the reactor according to IEC 60076-3

NOTE Not applicable for VSC reactors

283 3.2.4**284 magnetic shield**

285 the ferromagnetic part of a reactor designed for flux control purposes located outside the reactor
286 winding

287 NOTE This includes yokes, unwound limbs, magnetic tank shunts etc.

288 3.2.5**289 air-core reactor**

290 a reactor designed without any ferromagnetic material inside or outside the winding for flux
291 control purposes (usually dry-type reactors)

292 3.2.6**293 iron-core reactor**

294 a reactor designed with ferromagnetic material inside or outside the winding for flux control
295 purposes (usually dry-type reactors)

296 3.2.7**297 gapped-core reactor**

298 a reactor designed with a gapped ferromagnetic core inside the winding (usually liquid-
299 immersed reactors)

300 3.2.8**301 magnetically-shielded air-core reactor**

302 a reactor designed without any ferromagnetic material inside the winding but incorporating a
303 magnetic shield outside the winding for flux control purposes

304 3.2.9**305 air-core reactance of a gapped-core or magnetically-shielded air-core reactor**

306 the reactance calculated from the differential inductance (see Clause C.4) of a reactor which
307 contains ferromagnetic material for flux control purposes when all the ferromagnetic parts of
308 the reactor are fully saturated

309 3.2.10**310 magnetic characteristic**

311 The magnetic characteristic of a reactor is the relationship of the linked flux of the reactor
312 winding versus current (see Figure 3.1 and Figure 3.2).

313 NOTE The magnetic characteristic may be linear, non-linear or saturated as shown in Figure 3.1

314

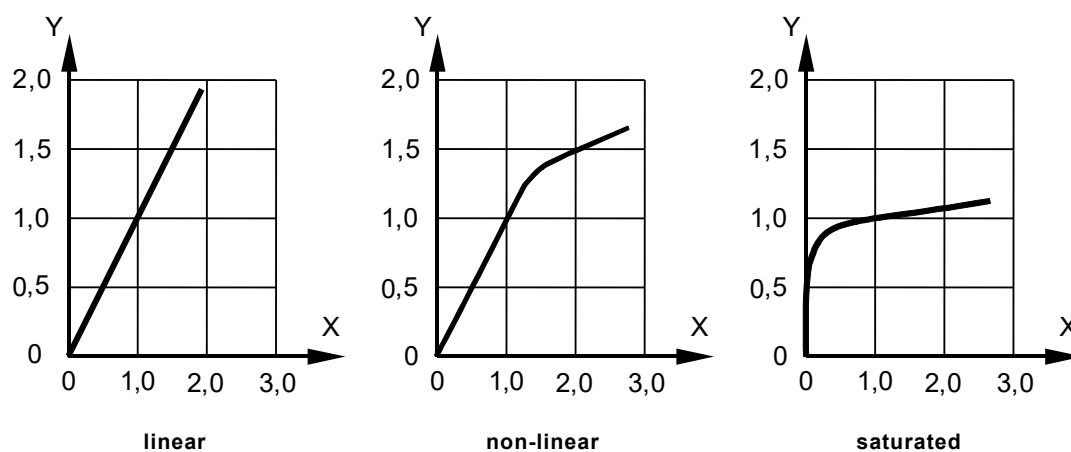


Figure 3.1 – Types of magnetic characteristics for reactors

Key

X axis – instantaneous value of current expressed in p.u. of the rated value

Y axis – instantaneous value of linked flux expressed in p.u. of the value at rated current

315

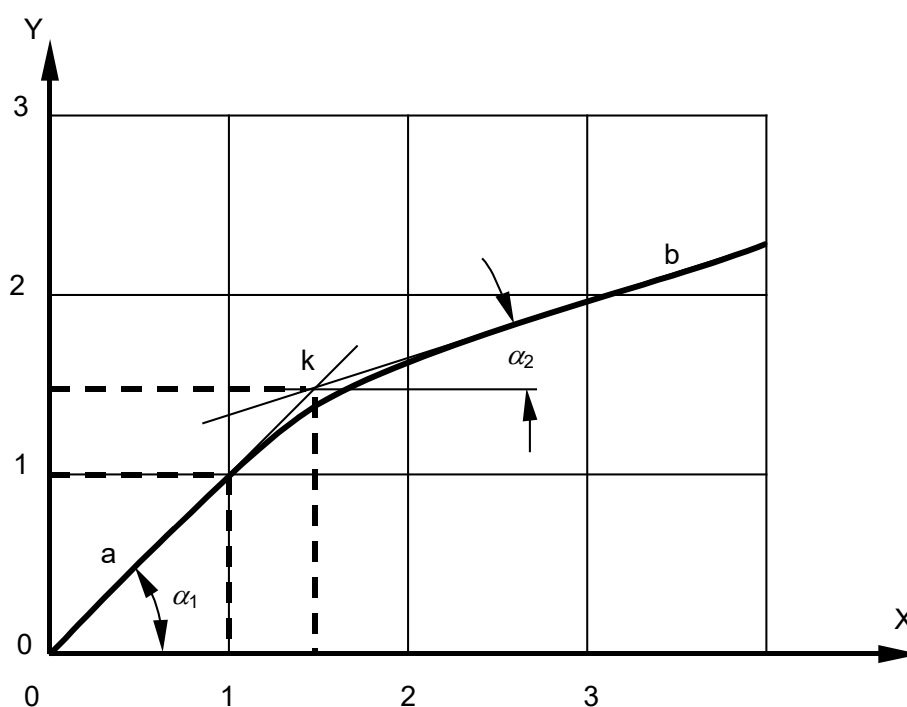


Figure 3.2 – Parameters for non-linear magnetic characteristic

Key

X axis – instantaneous value of current expressed in p.u. of the rated value

Y axis – instantaneous value of linked flux expressed in p.u. of the value at rated current

α_1 = slope angle (differential inductance) of the characteristic in the non-saturated part

α_2 = slope angle (differential inductance) of the characteristic in the saturated part

k = saturation knee point, intersection of the two straight lines a and b

3.2.11**linear reactor**

a reactor having a constant reactance (for smoothing reactors: a constant inductance) within the tolerance given in the relevant clause up to the relevant value of current or voltage

NOTE A linear reactor may have a linear magnetic characteristic as shown in the first graph of Figure 3.1 if there is no ferromagnetic component, or a non-linear magnetic characteristic as shown in the second graph of Figure 3.1 if the design incorporates a ferromagnetic core or shield.

3.2.12**saturated reactor**

a reactor specifically designed so that the reactance varies in value with the operating voltage or current

NOTE An example of a reactor with a saturated magnetic characteristic is provided in the third graph of Figure 3.1.

3.2.13**power frequency**

the rated frequency of the power system in which the reactor is to be installed

3.2.14**reference temperature**

for liquid-immersed reactors the reference temperature is as given in 60076-1; for dry-type reactors the reference temperature is as given in IEC 60076-11 according to the insulation class

NOTE For dry-type reactors where the temperature rise under normal operation is significantly less than that allowed for the particular insulation class a lower reference temperature should be agreed.

4 Symbols and abbreviations**Table 1 Symbols and abbreviations**

Symbol	Meaning	Units
A_x	Current meter reading	A
f	Frequency	Hz
f_{ac}	AC power frequency	Hz
f_r	Rated frequency (see NOTE)	Hz
f_{rd}	Rated discharge frequency	Hz
f_{rIN}	Rated inrush frequency	Hz
f_{rt}	Rated tuning frequency	Hz
h	Harmonic order	-
i	current	A
I_l	RMS current value of the fundamental harmonic	A
I_{equ}	Equivalent current at power frequency	A
$I_{equ\ test}$	Equivalent test current at test frequency	A
I_{ac}	Rated continuous a.c. current	A
$I_{ac-tmax}$	AC equivalent test current (IEC 60076-2)	A
I_{dc}	Rated continuous d.c. current	A
$I_{DC-meas}$	DC current at sound measurement	A
$I_{DC-rated}$	Rated DC current	A

Symbol	Meaning	Units
I_{dc-t1}	DC equivalent test current (IEC 60076-2)	A
I_h	Harmonic current of the h^{th} harmonic	A
I_{h-meas}	Harmonic current at sound measurement	A
$I_{h-rated}$	Rated harmonic current	A
I_{iT}	Test current	A
I_{Nr}	Rated continuous neutral current	A
I_{NSTr}	Rated short-time neutral current	A
I_{MSCr}	Rated mechanical short-circuit current	A
I_r	Rated current (see NOTE)	A
I_{ired}	Reduced test current	A
I_{rd}	Rated discharge current	A
I_{rIN}	Rated inrush current	A
I_{SCr}	Rated thermal short-circuit current (see NOTE)	A
I_T	Equivalent direct test current	A
I_{test}	Test current	A
$I_{test,AC}$	Equivalent power frequency test current	A
$I_{test,DC}$	Equivalent DC test current	A
I_{STr}	Rated short-time current	A
k	Coupling factor (see NOTE)	
L_d	Differential inductance	H
L_i	Sound power level of the individually tested harmonic component i	dB(A)
L_{inc}	Incremental inductance	H
L_{ired}	Sound level at harmonic frequency f_i at reduced test current I_{ired}	dB(A)
L_{iT}	Sound level at harmonic frequency f_i at full test current I_{iT}	dB(A)
L_r, L_{SCr}	Rated inductance (see NOTE)	H
L_{reac}	Inductance derived from reactance	H
L_{tot}	Total sound power	dB(A)
L_{W-meas}	Sound power of the reactor at DC and harmonic current during measurement	dB(A)
$L_{W-rated}$	Sound power of the reactor at rated DC and rated harmonic current	dB(A)
M	Mutual inductance	H
P_h	Total harmonic loss	W
P_{htot}	Sum of harmonic current losses corrected to reference temperature	W
P_{naux}	Losses at the n -th harmonic not contributing to the winding temperature rise	W
Q_f	Quality factor	
R	d.c. resistance	Ω
R_{DC}	Winding DC resistance corrected to reference temperature	Ω
R_{AC}	Measured winding power frequency resistance corrected to reference temperature	Ω
R_{actest}	Winding AC resistance at the n -th harmonic corrected to the max operating temperature	Ω
R_{ref}	d.c. resistance corrected to reference temperature	Ω
R_h	Winding AC resistance at test frequency corrected to the max operating temperature	Ω
T_1	Front time	s
T_d	Time above 90%	s

Symbol	Meaning	Units
T_{NSTr}	Rated short-time neutral current duration	s
THD_I	Total Harmonic Distortion for a current I	
T_r	Rated current duration	s
T_{SCr}	Rated thermal short-circuit current duration	s
T_{STr}	Rated short-time current duration	s
T_z	Time to first zero passage	s
U_{ac}	AC withstand voltage	V
U_{acmax}	Maximum phase to phase ac voltage (at reactor location)	V
U_{dcmax}	Maximum dc voltage (at reactor location)	V
U_d	Rated d.c. voltage	V
U_{dc}	DC withstand voltage or DC offset voltage for VSC converter reactor	V
U_{dmax}	Highest continuous d.c. voltage	V
U_m	Highest voltage for equipment (see IEC 60076-3, 3.1)	V
U_{max}	Maximum operating voltage, Maximum continuous voltage (see NOTE)	V
U_{pr}	Polarity-reversal test voltage	V
U_r	Rated voltage (see NOTE)	V
U_{test}	Test voltage	V
$U_{test,dc}$	DC test voltage	V
U_{tg}	Maximum operating voltage between terminal and ground	V
VD_h	Voltage drop at harmonic h	V
VD_{rss}	Voltage drop determined by the root-sum-square	V
V_x	Voltage meter reading	V
x	Exponent for correction oil temperature rise	-
X	Reactance	Ω
X_0	Zero-sequence reactance	Ω
X_{ac}	Reactance derived from AC voltage	Ω
X_m	Mutual reactance	Ω
X_r, X_{SCr}	Rated reactance (see NOTE)	Ω
y	Exponent for correction winding temperature rise	-
Z_h	Impedance at harmonic frequency f_h	Ω
Z_0	Zero-sequence impedance	Ω
Z_r	Rated continuous impedance	Ω
Z_{r1}	Rated single-phase continuous impedance	Ω
Z_{r3}	Rated three-phase continuous impedance	Ω
Z_{SCr}	Rated short-circuit impedance	Ω
Z_{SCr1}	Rated single-phase short-circuit impedance	Ω
Z_{SCr3}	Rated three-phase short-circuit impedance	Ω
Z_{STr}	Rated short-time impedance	Ω
Z_{STr1}	Rated single-phase short-time impedance	Ω
Z_{STr3}	Rated three-phase short-time impedance	Ω
φ	Linked flux	Wb

NOTE The definition of this rating is given in the relevant clause pertaining to the specific type of reactor.

5 Service conditions

5.1 General

Normal service conditions for reactors and the requirements for unusual service conditions are the same as those specified for power transformers in IEC 60076-1 and IEC 60076-11, as applicable.

The purchaser shall identify in his enquiry any service conditions not covered by the normal service conditions as specified in IEC 60076-1 and IEC 60076-11.

NOTE Examples of such conditions are:

- high or low ambient temperature outside the limits prescribed in IEC 60076-1;
- altitude in excess of the limits prescribed in IEC 60076-1;
- an environment with a pollution level (see IEC 60137 and IEC/TS 60815) that requires special consideration regarding the external insulation of the reactor or of the reactor itself; examples are:
 - damaging fumes and vapours;
 - excessive or abrasive dust;
 - industrial pollution;
 - salt spray;
 - tropical humidity.

This is of particular relevance to dry-type reactors. The manufacturer should state the measures to meet these pollution requirements (special coatings, weather shields etc.) and the maintenance requirements for these measures.

5.2 Seismic conditions

Reactors for operation under seismic conditions should be qualified by calculation in accordance with IEEE 693 or IEC 62271-300 for dry-type, subject to agreement between manufacturer and purchaser.

NOTE Further standards and/or national building codes may need to be considered subject to agreement.

5.3 Offshore platforms

Due to the increase of renewable generation more often offshore platform installations are required. Special consideration shall be given to the mechanical qualification of the structure due to continuous low frequency platform movement. Additionally, sea-fastening for platform transport from the wharf to the site may be required. It is recommended that international standards can be used as they become available, the reactor specification shall address specific requirements.

6 Design, testing, tolerances and application

The application of tests to reactors in general follows the corresponding rules for transformers in IEC 60076, but there may be special factors applicable to certain reactors, set out in this standard, which may limit the test levels achievable. Any limitations on the achievable test levels shall be made clear to the purchaser by the manufacturer at the time of tender.

Irrespective of the actual test levels achievable, reactors shall be designed to withstand the appropriate test levels specified in IEC 60076. Where exceptionally the actual test levels are below the levels given in IEC 60076 the manufacturer shall demonstrate to the purchaser by calculation and reference to other similar tested designs that the insulation, clearances and other relevant factors are adequate to meet the IEC 60076 test levels.

384 The tests shall be carried out with the reactor erected as in service, as far as features affecting
385 the test results are concerned.

386 For type testing of dry-type air-core reactors, the same principles shall be applied, the reactor
387 shall be erected with all accessories that can influence the result of the particular test such as
388 sound enclosure, top hats, skirts, corona/grading rings, bus work and electromagnetic shielding
389 elements. Routine tests may be carried out on partly assembled units (e.g. without top hats,
390 skirts, sound enclosure)

391 IEC 60076-1 applies to the ambient temperature for test, however dry-type reactors shall be
392 tested at an ambient temperature between 10°C and 40°C. If such temperature range cannot
393 be achieved by the supplier (e.g. some outdoor tests due to the size of the equipment) this shall
394 be clearly stated by the manufacturer in the offer and agreed with the purchaser.

395 The purchaser may request calculations and/or comparison with similar rated units instead of
396 type or special tests where these tests have been previously performed on similar units.

397 As the power factor of reactors is normally very low, the measurement of loss using analog
398 wattmeters may be subject to considerable errors. The measurement of loss using flux
399 compensated current transformers, standard capacitors as voltage transducers and digital
400 wattmeters may provide the required accuracy. A suitable bridge method may also provide the
401 required accuracy. For more information see IEC 60076-8. At the purchaser's request,
402 satisfactory documentation regarding the accuracy of the proposed method shall be provided.

403 A dry-type reactor is generally not enclosed in a steel tank or enclosure. All parts of the reactor
404 assembly shall be considered as live. Therefore, consideration shall be given to prevention of
405 accidental contact by personnel when the reactor is in service. If the purchaser has a particular
406 requirement for the reactor to be mounted in an elevated position this shall be stated in the
407 tender. Safety precautions such as fencing are likely to be required and shall be considered as
408 part of the substation design. Where there are specific limits for the magnetic field strength
409 specified by the purchaser, the manufacturer shall supply a plot indicating the magnetic field
410 strength in the vicinity of the reactor.

411 The magnetic field in the immediate vicinity of a dry-type air-core reactor may be of sufficient
412 magnitude to induce heating and reaction forces in nearby metallic objects. Where applicable,
413 guidance concerning the appropriate magnetic clearance is to be supplied by the manufacturer.

414 The temperature, at specified maximum ambient temperature, of the winding terminals of dry-
415 type reactors shall not exceed the limits given in Table 2.

416 **Table 2 - Temperature limits for winding terminals of dry-type reactors**

	Temperature
bare terminals of copper, copper alloy, aluminium or aluminium alloy:	90 °C
silver-plated or nickel-plated terminals made of copper, copper alloy, aluminium or aluminium alloy:	115 °C
tin-plated terminals made of copper, copper alloy, aluminium or aluminium alloy:	105 °C

417
418 For more information see IEC 60943.

419 Tolerances on certain rated and guaranteed values are given in the relevant clauses. For other
420 quantities when they are subject to guarantees, reference shall be made to IEC 60076-1, as
421 applicable.

422 NOTE Other tolerances and tolerances on other quantities may be specified in the enquiry and in the order.

7 Shunt reactors

7.1 General

This clause describes the requirements for reactors that are intended for connection phase-to-earth, phase-to-neutral or between phases in a power system to compensate for capacitive current. The absorbed reactive power at rated voltage can be fixed, or it may be adjusted by the use of additional means such as:

- phase-controlled switching by a power electronic device (e.g. in a static var scheme);
- d.c. magnetisation of the iron core;
- winding tapping for on-load or off-load setting;
- mechanically movable cores.

NOTE Information on special applications is given in Annex A.

The reactor has to be designed for daily switching operation

7.2 Design

With regard to design and installation the reactor is identified as:

- single-phase or three-phase;
- dry-type or liquid-immersed;
- air-core or gapped-core;
- with or without magnetic shield;
- for indoor or outdoor installation;
- fixed or variable reactance;
- for variable reactors: variation in reactance by movable core or with tapplings in winding;
- linear or saturated;
- with or without auxiliary windings (supply of auxiliary system).

Knowledge of the magnetic characteristic may be necessary for the purchaser and shall be provided on request. It may be determined by measurement or by calculation. For detailed information see Annex C.

In case of a variable reactor with tapplings and an OLTC special care has to be taken with selecting the OLTC. The leakage impedance between coarse and fine regulating winding can be a limiting factor for the OLTC and has to be checked between Reactor manufacturer and the OLTC manufacturer.

7.3 Definitions

7.3.1

rated voltage U_r

the voltage at rated frequency assigned to be applied between the line terminals of a winding of a three-phase reactor, or between the terminals of a winding of a single-phase reactor.

NOTE For single-phase reactors intended to be associated in a three-phase bank, the rated voltage of each individual unit intended for star connection is indicated by a fraction, in which the numerator is the line-to-line voltage and the denominator is $\sqrt{3}$, for example:

$$U_r = \frac{525}{\sqrt{3}} \text{ kV}$$

7.3.2**maximum operating voltage $U_{\max}$**

the specified highest voltage at rated frequency at which the reactor shall be capable of operating continuously

NOTE $U_{\max}$ is not the same as U_m (see 3.2.3) but in particular cases it may have the same value.

7.3.3**rated power**

the reactive power of the shunt reactor specified for operation at rated voltage and rated frequency.

In the case of reactors with adjustable reactance, the rated power refers to the setting of the reactor with highest reactive power, unless otherwise specified.

NOTE In the case of tapped reactors, the rated power refers to the tapping position with the minimum number of effective turns.

7.3.4**Minimum power**

in case of reactors with adjustable reactance. For tapped reactors this is the tap position with the maximum effective turns and for mechanically adjustable units at the minimum airgap.

7.3.5**Maximum power**

in case of reactors with adjustable reactance. For tapped reactors this is the tap position with the minimum effective turns and for mechanically adjustable units at the maximum airgap.

7.3.6**Minimum number of steps**

in case of reactors with adjustable reactance by tapplings.

NOTE in case of a reactor with movable core the adjustment range is typically 1:5

7.3.7**rated current I_r**

the line current derived from rated power and rated voltage

NOTE For single-phase reactors intended to be associated in a three-phase bank, the rated current of each individual unit intended for delta connection is indicated by a fraction in which the numerator is the corresponding line current and the denominator is $\sqrt{3}$, for example:

$$I_r = \frac{500}{\sqrt{3}} \text{ A}$$

For reactors used in a static var scheme with phase-controlled current the rated current is referred to the full load current with a sinusoidal waveform unless otherwise specified.

7.3.8**rated reactance (rated inductance) X_r (L_r)**

the reactance specified at rated voltage and rated frequency in ohms per phase. It is derived from rated power and rated voltage. For reactors with phase-controlled current, the rated inductance ($L_r = X_r / (2\pi f_r)$) shall be specified.

7.3.9**zero-sequence reactance of a three-phase star-connected reactor X_0**

the reactance per phase at rated frequency equal to three times the value of reactance measured between the line terminals connected together and the neutral terminal. The ratio X_0/X_r depends upon the reactor design. For more information see Annex D.

7.3.10**mutual reactance of a three-phase reactor X_m**

the ratio between the induced voltage in an open phase and the current in an excited phase at rated frequency in ohms per phase. It is normally expressed as per unit of the rated reactance.

7.3.11**inrush current level**

the ratio of the maximum peak current which may occur during reactor energizing and $\sqrt{2}$ times the rated current

7.4 Rating

The rating of a shunt reactor refers to continuous duty, unless otherwise specified.

For reactors used in a static var source scheme with phase-controlled current the guaranteed values are referred to full load current with sinusoidal waveform unless otherwise specified.

7.4.1 Rated voltage

The rated voltage U_r at rated frequency is assigned by the purchaser. The rated voltage provides the basis for the design, the manufacturer's guarantees and the tests unless otherwise specified in 7.9. The rated voltage would usually be specified as the normal operating voltage of the power system.

7.4.2 Maximum operating voltage

The maximum operating voltage U_{max} is specified by the purchaser. It shall not be less than the highest continuous operating voltage applied to the reactor in service. It may be equal to the rated voltage U_r .

7.4.3 Rated power

The rated power shall be specified by the purchaser.
For variable reactors this will be the maximum power

7.4.4 Zero-sequence reactance of a three-phase star-connected reactor

Any specific ratio X_0/X_r preference shall be stated by the purchaser at the time of enquiry and shall be agreed between purchaser and manufacturer at the time of order.

NOTE For more information on the design dependence of the zero-sequence reactance see Annex D.

7.4.5 Mutual reactance of a three-phase reactor

The maximum value of the mutual reactance X_m may be specified by the purchaser if it is important for the system.

NOTE 1 The mutual reactance will generally be negligible for:

- a bank of three separate single-phase liquid-immersed reactors;
- a bank of three single-phase air-core (dry-type) reactors in a side-by-side arrangement;
- a three-phase reactor having a magnetic shield for zero-sequence flux.

NOTE 2 For more information on the design dependence of the mutual reactance see Annex D.

7.4.6 Inrush current level

Unless otherwise specified, the maximum peak inrush current calculation is based on rated voltage U_r , rated frequency and most onerous switching angle. The inrush current level shall be provided by the manufacturer on purchaser request.

NOTE More information on the inrush current characteristic is given in Annex C.6.

7.4.7 Linearity of the shunt reactor

Unless otherwise specified, the reactor shall be a linear reactor within the tolerance given in 7.11.2 up to U_{max} . Alternatively a maximum harmonic current as a percentage of the fundamental component may be specified at U_r or U_{max} .

7.5 Temperature rise

The temperature rise limits given in IEC 60076-2 for liquid-immersed transformers and in IEC 60076-11 for dry-type transformers apply at the maximum operating voltage U_{max} .

7.6 Insulation level

For specification of the insulation level see IEC 60076-3.

7.7 Sound level specification

The sound level development of shunt reactors is physically inevitable and within limits only controllable by design. Typical ranges of sound power levels for liquid-immersed shunt reactors for specification support are provided in CIGRE Technical Brochure 655 "Technology and utilisation of oil-immersed shunt reactors".

NOTE At the time of writing this standard, equivalent information for dry-type shunt reactors was not available.

7.8 Rating plates

Each reactor shall be provided with a rating plate of weatherproof material, fitted in a visible position, showing in all cases the appropriate items indicated below. The entries on the plate shall be indelibly marked (for example by etching, engraving or stamping).

- Type of reactor;
- Outdoor/indoor application;
- Number of this standard;
- Manufacturer's name;
- Manufacturer's serial number;
- Year of manufacture;
- Insulation level(s);
- Number of phases;
- Rated power (for tapped reactors the power on each tapping position);
- Rated frequency;
- Rated voltage;
- Rated current;
- Maximum operating voltage;
- Winding connection (where applicable);
- Reactance at rated voltage and frequency or inductance at rated voltage, measured value;

- 584 • Type of cooling;
- 585 • Thermal class of insulation (for dry-type reactors only);
- 586 • Temperature rise of top-oil and average winding or rated temperature of external cooling
- 587 medium (for liquid-immersed reactors only);
- 588 • Total mass;
- 589 • Transportation mass (for liquid-immersed reactors);
- 590 • Untanking mass (for liquid-immersed reactors);
- 591 • Mass of insulating liquid (where applicable);
- 592 • Type of insulating liquid, if not mineral oil (where applicable);
- 593 • Connection diagram showing tapplings and instrument transformers (where applicable);
- 594 • Type of tap changer (where applicable);
- 595 • Zero-sequence reactance, measured value (where applicable on request);
- 596 • Mutual reactance, measured value (where applicable on request).

597

598 **7.9 Tests**

599 **7.9.1 General**

600 The general requirements for routine, type and special tests are prescribed in IEC 60076-1.

601 **7.9.2 Routine tests**

602 The following routine tests shall be performed:

- 603 • measurement of winding resistance;
- 604 • measurement of reactance (7.9.5);
- 605 • measurement of loss at ambient temperature (7.9.6);
- 606 • tests on on-load tap-changers, where appropriate (7.9.10);
- 607 • measurement of acoustic sound level for liquid-immersed reactors (7.9.13);
- 608 • dielectric tests (7.9.11);
- 609 • measurement of insulation resistance and/or capacitance and dissipation factor ($\tan \delta$) of
- 610 the winding insulation to earth for liquid-immersed reactors. (These are reference values for
- 611 comparison with later measurements in the field. No limitations for the values are given
- 612 here.);
- 613 • leak testing with pressure for liquid-immersed reactors (tightness test);
- 614 • check of core, magnetic shield and frame insulation for liquid immersed reactors with core
- 615 or frame insulation.

616

617 **7.9.3 Type tests**

618 The following type tests shall be performed:

- 619 • temperature rise test (7.9.15);
- 620 • measurement of acoustic sound level close to service temperature (for liquid-immersed and
- 621 dry-type reactors) (7.9.13);
- 622 • measurement of vibration for liquid-immersed reactors (7.9.14);
- 623 • dielectric tests (7.9.11);
- 624 • measurement of power consumption of fans and oil pumps, if any.

7.9.4 Special tests

The following special tests shall be performed when specifically requested by the purchaser:

- measurement of zero-sequence reactance on three-phase reactors (7.9.8);
- measurement of mutual reactance on three-phase reactors (7.9.9);
- measurement of harmonics of the current (7.9.7);
- measurement of loss close to reference temperature in the case of liquid-immersed reactors (7.9.6);
- determination of linearity of reactance (7.9.5.3);
- measurement of magnetic characteristic for gapped-core reactors and magnetically-shielded air-core reactors (7.9.12);
- dielectric tests (7.9.11);
- vacuum deflection test on liquid immersed reactors;
- pressure deflection test on liquid immersed reactors;
- vacuum tightness test on site on liquid immersed reactors;
- measurement of frequency response (Frequency Response Analysis or FRA);
- check of external coating (ISO 2178 and ISO 2409 or as specified);
- mechanical test or assessment of tank for suitability for transport (to customer specification).

7.9.5 Determination of reactance and linearity of reactance

7.9.5.1 Method

- a) The reactance shall be determined at rated frequency by applying an approximately sinusoidal voltage.
- b) The reactance is determined from the applied voltage and the measured current (r.m.s. value). It is assumed that the resistive component of impedance is negligible.
- c) The reactance of three-phase reactors shall be measured with symmetrical three-phase voltages applied to the reactor terminals.

The reactance shall be taken as

$$\frac{\text{line-to-line applied voltage}}{\text{average measured line current} \cdot \sqrt{3}}$$

equation 1

NOTE 1 Consideration should be given to the possible flow of zero-sequence current through the shunt reactor under test. This may impact the test result.

NOTE 2 For three-phase reactors with a magnetic shield for zero-sequence flux, by special agreement between manufacturer and purchaser, a reactance measurement may be made with single-phase excitation. In this case a comparison at a lower voltage between single-phase and three-phase measurements must be made and a suitable correction factor agreed upon.

7.9.5.2 Measurement of reactance at rated voltage (routine test)

The measurement of the reactance shall be made according to 7.9.5.1 at rated voltage and rated frequency except for air-core reactors. In this case, measurements shall be made at rated frequency at any voltage up to rated voltage.

For variable reactors the reactance shall be measured at rated voltage in the two extreme tap positions. For tapped reactors all other tap positions will be measured at $\geq 20\%$ of the rated voltage. This lower test voltage is needed to limit the rebalancing the capacitor bank in the test facility.

In exceptional cases, for example in the case of reactors with extremely large rated power and high system voltage, it may be difficult to perform the test at rated voltage. For gapped-core reactors and magnetically-shielded air-core reactors designed to be linear, the test voltage shall be the maximum available from the test plant but at least $0,9 \cdot U_r$. In this case the reactor shall be shown to be a linear reactor according to 7.9.5.3. If the manufacturer is not able to measure at U_r then the achievable test level shall be stated in the tender.

7.9.5.3 Determination of linearity of reactance (special test)

The reactance shall be measured with the method as described in 7.9.5.1 at $\leq 0,5 \cdot U_r$, $0,7 \cdot U_r$, $0,9 \cdot U_r$, U_r and $U_{\max}$ or other specified voltages up to maximum operating voltage or, by agreement between purchaser and manufacturer, slightly above this value.

For variable reactors this will be measured in the tap position with the maximum power.

Where the test plant is not adequate to perform the test at these voltages or it is desired to determine the linearity above $U_{\max}$ the test may be done at a lower frequency (and the corresponding lower voltage). Alternatively, the reactor may be shown to be linear by measurement of the magnetic characteristic according to 7.9.12 and the reactor reactance numerically calculated from this characteristic for the required voltage levels.

For a three-phase reactor having a magnetic shield for zero-sequence flux this test can be performed single phase in agreement between purchaser and manufacturer.

NOTE 1 For more information see also Annex C.

NOTE 2 Not applicable for air-core reactors

7.9.6 Measurement of loss (routine test, special test)

7.9.6.1 General

Satisfactory documentation regarding the accuracy of the proposed method shall be provided on request.

For three-phase reactors the measurement of loss shall be performed under three-phase excitation.

For variable reactors the loss measurement should be done in the minimum and maximum power tap positions or core positions.

NOTE 1 In case of low loss three-phase reactors the measured loss of the individual phases may be unequal or even negative in one phase. The arithmetic sum of the three loss values gives the total loss.

NOTE 2 For three-phase reactors with a magnetic shield for zero-sequence flux, by special agreement between manufacturer and purchaser, a measurement of loss may be made with single-phase excitation. In this case, a comparison, at lower voltage, between single-phase and three-phase measurement must be made and a suitable correction factor agreed upon.

7.9.6.2 Air-core reactors

For air-core reactors the measurements may be made at any voltage up to rated voltage at rated frequency. The loss at rated voltage shall be obtained by multiplying the measured loss by the square of the ratio of rated voltage to the voltage measured.

Metal parts belonging to the support structure when supplied by the manufacturer of the reactor, that might affect the measurement of loss, shall be in place for the test.

NOTE The presence of metal parts in the vicinity around or under reactors will significantly affect the measurement of loss. Therefore metal parts that belong to the support structure of the reactor shall be present during the test and other metal parts shall be avoided (green field). For large Mvar reactors a green field measurement as a type test might be required to determine the unaffected reactor losses. In such case a correction factor obtained at the factory tested losses and the green field losses may be applied for routine testing.

The total loss is composed of ohmic loss and additional loss. The ohmic loss portion is taken to be equal to $I_r^2 \cdot R$, R being the measured d.c. resistance, I_r being the rated current. The additional loss portion is the difference between the total loss and the ohmic loss $I_r^2 R$.

The measurement of loss may be performed at an ambient temperature between 10 °C and 40 °C and corrected to reference temperature according to the method given in IEC 60076-1.

NOTE 1 The loss measurement of TCR (Thyristor Controlled Reactor) should be performed at the fundamental frequency and on the odd harmonics up to the 13th order, unless otherwise specified by the purchaser. Typically higher harmonics have negligible contribution to the losses.

NOTE 2 For two stacked air core reactors as a type test the inductance, loss and quality factor shall be measured with the reactor assembled as in service. For the routine test, inductance, loss and quality factor measurements on individual coils may be used taking into account the coupling factor and additional losses from the type test.

7.9.6.3 Gapped-core reactors and magnetically-shielded air-core reactors

For gapped-core reactors and magnetically-shielded air-core reactors the loss shall be measured at rated voltage and rated frequency. The voltage shall be measured with a voltmeter responsive to the mean value of voltage but scaled to read the r.m.s. value of a sinusoidal wave having the same mean value. If, at rated voltage, the current measured is different from the rated current, the measured loss shall be corrected to rated current by multiplying the measured loss with the square of the ratio of rated current to measured current.

In exceptional cases, for example extremely large rated power and high system voltage, it may be difficult to meet this test condition. In these cases, the loss at rated current shall be obtained by multiplying the measured loss by the square of the ratio of rated current to the current measured at the reduced voltage. The test voltage shall be at least $0,9 \cdot U_r$.

The total loss is composed of ohmic loss, iron loss and additional loss. The ohmic loss portion is taken to be equal to $I_r^2 \cdot R$, R being the measured d.c. resistance, I_r being the rated current. Iron loss and additional loss cannot be separated by measurement. The iron loss is given by calculation. The additional loss is the result of the total loss minus the ohmic loss and the iron loss.

The measurement of loss shall be performed as a routine test at the factory ambient temperature and corrected to reference temperature. The ohmic loss and the additional loss are corrected to reference temperature according to the method given in IEC 60076-1. The iron loss is not affected by the temperature and kept constant.

When a special measurement of loss test close to reference temperature is specified, the measurement of loss can be performed in conjunction with the temperature rise test. The routine measurement of loss at ambient temperature shall also be made on the same unit to establish a temperature coefficient for total loss (assuming linear variation). The loss figure of a reactor

757 of the same design shall be corrected to reference temperature using the temperature
758 coefficient established on this unit.

759 NOTE Annex E gives an example of temperature correction of losses.

760 **7.9.7 Measurement of harmonics of the current (special test)**

761 The harmonics of the current in all three phases are measured at rated voltage or, if specified
762 at maximum operating voltage, by means of a harmonic analyser. The magnitude of the relevant
763 harmonics is expressed as a percentage of the fundamental component. Alternatively or if the
764 voltage test level cannot be achieved, the harmonics of the current at rated voltage or maximum
765 operating voltage as specified can be derived from the measured magnetic characteristic or by
766 calculation. For more information on the magnetic characteristic see Annex C.

767 For variable reactor this test shall be performed at maximum power.

768 The harmonics of the applied voltage shall be adequately measured at the same time.

769 NOTE 1 Unless the purchaser has particular harmonic current requirements this test is not normally performed on
770 linear shunt reactors. Due to the linear impedance characteristic of air-core reactors, this type of equipment
771 will not introduce harmonic currents. If measurement at harmonic frequencies is required, harmonic content
772 shall be specified by the customer.

773 NOTE 2 This measurement is practicable only if the distortion factor (see clause C.5) of the applied voltage is less
774 than 2 %.

775

776 **7.9.8 Measurement of zero-sequence reactance on three-phase reactors (special test)**

777 See IEC 60076-1.

778 This measurement shall be carried out at a voltage corresponding to a neutral current not
779 exceeding the rated phase current. The current in the neutral and the duration of application
780 may be limited to avoid any metallic constructional parts reaching an excessive temperature.

781 For variable reactors this test shall be performed in the tap position with the maximum power.

782 **7.9.9 Measurement of mutual reactance on three-phase reactors (special test)**

783 Unless otherwise specified the measurement shall be made at rated voltage according to Figure
784 7.1 for gapped-core reactors and magnetically-shielded air-core reactors. For other reactors
785 any convenient voltage, depending on available test equipment, may be used for this
786 measurement. The induced voltage measurement shall be measured with a voltmeter
787 responsive to the mean value of voltage but scaled to read the r.m.s. value of a sinusoidal wave
788 having the same mean value.

789 For variable reactor this test shall be performed in the tap position with the maximum power.

790 The current in the neutral and the duration of application may be limited to avoid any metallic
791 constructional parts reaching an excessive temperature.

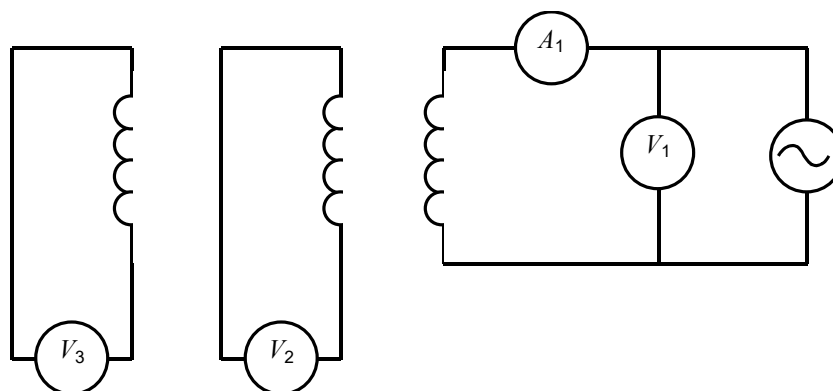


Figure 7.1 - Measurement of mutual reactance for three-phase reactors or banks of three single-phase reactor

Key

V_1 , V_2 , V_3 – voltmeter reading

A_1 – currentmeter reading

Mutual reactance $X_m = V_2/A_1$ or V_3/A_1 respectively

7.9.10 Test on on-load tap-changers

With the tap-changer fully assembled on the reactor, the following sequence of operations shall be performed without failure:

NOTE The sequence of tests on the tap-changer can be performed during the Factory acceptance test of the reactor and does not need to be performed in one sequence. Also the order of tests is open.

- a) With the reactor de-energized, eight complete cycles of operation (a cycle of operation goes from one end of the tapping range to the other, and back again).
- b) With the reactor de-energized, and with the auxiliary voltage reduced to 85% of its rated voltage, one complete cycle of operation.
- c) Switching capacity test. With current and voltage at maximum operating (U_{Max}), operate the tap-changer in one reduced cycle; start 2 tap positions away from minimum turn position, tap to minimum turn position and back to the start position. Totally four operations. In case of windings with different number of turns per step using an OLTC without change-over selector for regulation, switching capacity test has to be agreed between manufacturer and purchaser.
- d) With current and voltage at maximum operating voltage (U_{Max}) in the tap winding, 10 cycles of tap-change positions across the range of two steps on each side from where a coarse or reversing change over selector operates. (This last test is not applicable for regulation schemes without change-over selector).

If the manufacturer is not able to perform one or more of the above tests, this shall be stated in the tender and details of the test has to be agreed at time of order. Test C and D requires an power supply in the test facility which can handle large power steps. This can be difficult or not possible at a test facility with a small generator or static convertor as a power supply.

NOTE Tests a and b are intended to check mechanically the operation of the tap changer. The tap changer is installed in the reactor and the motor drive and drive shafts are installed. There can be higher friction or misalignments and this is recommended to be checked.

Test c is a test to operate the tap changer at maximum current and maximum operating voltage. This test is also performed as a type test at the tap changer manufacturer and may be agreed to be carried out at reduced voltage level.

Test d is a test to test the inductive switching condition at the change-over selection. Tie-in measures for the change-over switch are calculated by the tap-changer manufacturer, based on the capacitive coupling, provided by the manufacturer of the reactor. Contrary to power transformers, in reactor applications every switching operation is an inductive switching operation. Especially in coarse/fine winding arrangements, the mid-position represents the most severe inductive switching condition. For the proper selection of the diverter switch and the correct transition resistor, the OEM has to deliver the stray inductance values between the coarse winding and the tap winding. The only possibility to check these calculations is to operate the tap-changer at maximal operating voltage across the mid-position.

7.9.11 Dielectric tests

7.9.11.1 General

The application of dielectric tests to shunt reactors in general follows the corresponding rules for transformers in IEC 60076-3, IEC 60076-4 and IEC 60076-11.

7.9.11.2 Applied voltage test (routine test, special test)

This test applies as a routine test for liquid-immersed reactors and dry type reactors with a core or screen. See clause 10 of IEC 60076-3.

Dry-type air-core reactors usually employ standard station post or bus support insulators to form the reactor mounting and the insulation between reactor windings and earth, and between phases where two or more units are stacked. Therefore this test is a test of the support insulators and will only be performed as a special test when specifically requested.

NOTE Unless otherwise indicated in the tender by the manufacturer the support insulators are assumed to be designed according to IEC 60273 and tested in accordance with IEC 62217 for polymeric HV insulators and IEC 62231 for composite station post insulators.

7.9.11.3 Induced voltage test (routine test)

Test voltages and the relevant test methods as specified in IEC 60076-3 shall be agreed between manufacturer and purchaser at the time of the order.

The induced voltage test of reactors requires a high reactive power level at a high voltage level. A supply suitable for the high voltage level and the full power rating is necessary.

For variable reactors this test will be performed in the tap position with the maximum power.

Exceptionally, the required test level according to IEC 60076-3 for the induced voltage tests may not be practically achievable when testing large reactors. Any restrictions in the test levels achievable shall be stated by the manufacturer in the tender. In this case, by agreement between purchaser and manufacturer, the induced voltage test may be performed at lower levels or by lightning impulse tests for reactors with $U_m < 170$ kV or by additional lightning impulse tests and switching impulse tests for reactors with $U_m \geq 170$ kV.

Furthermore special considerations apply to single-phase tests on three-phase reactors without magnetic shield for zero-sequence flux.

Reactors with $U_m \leq 72,5$ kV and uniform insulation shall be tested according to IEC 60076-3:2013, 11.2 (Induced voltage withstand test IVW) with a (phase to earth) test voltage of $(2xU_r)/\sqrt{3}$. If agreed by the purchaser this test may be substituted by an IVPD test with an enhancement voltage of $(2xU_r)/\sqrt{3}$ see 7.3.1.3a of IEC 60076-3.

Reactors with $72,5$ kV $< U_m \leq 170$ kV and uniform insulation shall be tested according to IEC 60076-3:2013, 11.2 (induced voltage withstand test IVW) and 11.3 (IVPD) with a (phase to earth) test voltage of $(2xU_r)/\sqrt{3}$. Single-phase reactors shall be tested with the test level equal to two times the rated voltage across the winding.

867 If the power and voltage requirements for the enhancement voltage level exceeds those
868 available at the test station this shall be stated by the manufacturer in the tender. In this case,
869 the enhancement voltage level may be reduced or omitted and the test duration extended by
870 agreement between purchaser and manufacturer. Alternatively, three single phase tests may
871 be agreed between purchaser and manufacturer as applied to reactors with $U_m > 170$ kV.

872 **Reactors with $72,5 \text{ kV} < U_m \leq 170 \text{ kV}$ and non-uniform insulation** shall be tested according
873 to IEC 60076-3:2013, 11.2 (IVW) and 11.3 (IVPD).

874 Additionally an Line terminal AC withstand voltage test (LTAC) shall be performed at the test
875 level given for the applied voltage test applicable to the line terminal in Table 2 of IEC60076-
876 3 using the method given in Clause 12 of IEC60076-3. This test may be omitted if a switching
877 impulse test is performed by agreement between manufacturer and purchaser.

878 An induced voltage withstand test shall be performed according the method given in 11.2
879 (induced voltage withstand test IVW) with a (phase to earth) test voltage of $(2 \times U_r)/\sqrt{3}$. The
880 excitation circuit applicable for all types of reactor design for the phase-to- earth test according
881 to clause 12 is given in Figure 7.2. In this case the neutral will be subjected to a voltage of
882 $1/3 \cdot U_{\text{test}}$. In the special case of a reactor design with a magnetic shield for zero-sequence flux,
883 the test circuit given in Figure 7.4, may also be used. In this case there is no voltage stress on
884 the neutral.

885 By agreement between manufacturer and purchaser the three-phase test may be replaced by
886 three single-phase tests as shown in Figure 7.3. In this case the test level is equal to $2 \cdot U_r/\sqrt{3}$.

887 NOTE During this test the voltage between phases is lower by a factor of $1,5/\sqrt{3}$ than for a three-phase test.

888 For single-phase reactors tests according to clause 11.2, 11.3 and 12 of IEC 60076-3:2013
889 apply. For the test according to clause 12 the voltage at the neutral terminal may be raised by
890 connection to an auxiliary booster transformer to limit the test voltage across the winding to two
891 times the rated voltage across the winding. In such cases the neutral shall be insulated
892 accordingly.

893 If the power and voltage requirement for these tests exceeds those available at the test station,
894 this shall be stated by the manufacturer in the tender.

895 In this case, the enhancement voltage level may be reduced or omitted and the test duration
896 extended by agreement between purchaser and manufacturer.

897 **Reactors with $U_m > 170 \text{ kV}$ and non-uniform insulation** shall be tested according to
898 IEC 60076-3:2013, 11.3 (Induced voltage test with partial discharge measurement (IVPD)), but
899 for three-phase reactors the test may be performed as a three-phase test or as three single-
900 phase tests with an excitation circuit as given in Figure 7.3. If the power and voltage requirement
901 for these tests exceeds those available at the test station, by agreement between manufacturer
902 and purchaser, the short-time application of the enhancement voltage level may be reduced or
903 omitted and the test duration extended.

904 If the power and voltage requirement for these tests exceeds those available at the test station,
905 for reactors with a magnetic shield for zero-sequence flux, the single-phase test application as
906 given in Figure 7.4 may be agreed between purchaser and manufacturer.

907 NOTE The circuit shown in Figure 7.4 is not in accordance with IEC 60076-3, 12.4, Figure 3. In the circuit shown
908 in Figure 7.4, the voltage induced along the windings is equal to the voltage induced during the test
909 according 12.4 but the voltage between windings of different phases is only 2/3 of the voltage induced
910 during the test according 12.4 and is slightly less than U_m .

911

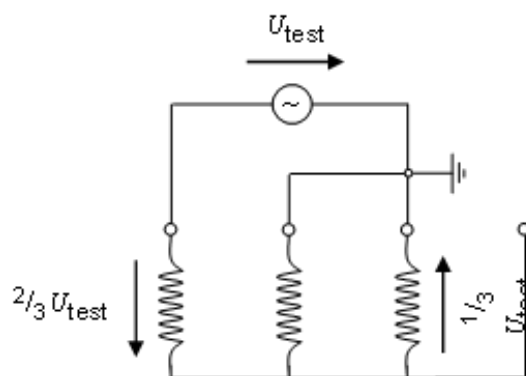


Figure 7.2 -Phase-to-phase test circuit for single-phase excitation

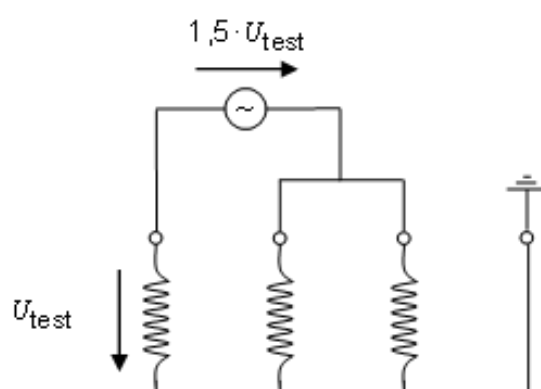


Figure 7.3 – Phase-to-phase test circuit

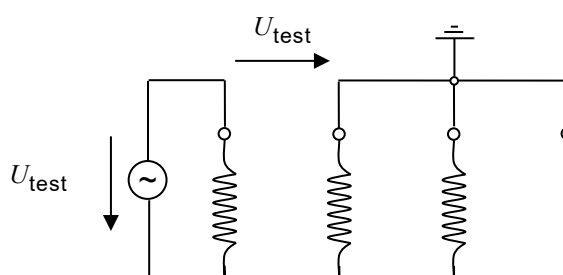


Figure 7.4 - Single-phase excitation circuit for reactors with magnetic shield for zero-sequent flux

Dry-type reactors shall be tested as single-phase units. By agreement between purchaser and manufacturer the induced AC withstand voltage test may be replaced by additional lightning impulse voltage tests. Alternatively, the turn-to-turn overvoltage test as described in Annex F may be used as a replacement test for equipment with $U_m \leq 36$ kV unless otherwise specified.

7.9.11.3.1 Induced AC withstand voltage test for Dry Type reactors (routine test)

Dry-type reactors shall be tested each single-phase unit individually. The induced AC withstand voltage test for dry type reactors can be performed by 3 alternative methods, depending on the supplier's test plant and the reactive power level available.

The relevant test method shall be stated by the manufacturer at the time of the quotation and agreed with the purchaser at time of order.

- a) Induced Voltage Withstand test (IVW) according to IEC 60076-3-2013, clause 11.2. This test is normally not feasible because of the high reactive power level required from the test plant supply.

or

- b) Lighting Impulse voltage test (LI) according to IEC 60076-3-2013, clause 13. Considering the non-linear distribution of the voltage along the winding turns, the impulse test sequence shall be applied to each line terminal of the winding in succession. The other line terminal shall be earthed directly or, if needed to achieve the required wave shape, through an impedance. Due to the low impedance of the reactor for tertiary connected units, the standard wave shape usually cannot be met. For more information see IEC 60076-4, Annex A.3.

or

- 935 c) The turn-to-turn overvoltage test as described in Annex F may be used as a replacement
936 test for equipment with $U_m \leq 36$ kV unless otherwise specified.

937 **7.9.11.4 Lightning impulse test (routine test)**

938 A lightning impulse test including chopped waves shall be a routine test for liquid-immersed
939 reactors, see clauses 13 and 14 of IEC 60076-3 and clause 7 of IEC 60076-4.

940 For variable reactors each phase will be tested in a different tap position. These tap positions
941 are the two extreme tap positions and the middle tap position (equal to transformer testing)

942 For dry-type reactors a lightning impulse test according to clause 13 of IEC 60076-3 and clause
943 7 of IEC 60076-4 shall be applied. Alternatively, the turn-to-turn overvoltage test as described
944 in Annex F may be used for reactors with $U_m \leq 36$ kV as a replacement test unless otherwise
945 specified.

946 In the case of a variable reactor LIN in tap position with minimum power.

947 **7.9.11.5 Wet lightning impulse test applicable for dry-type reactors (special test)**

948 When specified, the wet lightning impulse test shall be performed as described in 7.9.11.4 and
949 with application of water spray as described in clause 9 of IEC 60060-1.

950 **7.9.11.6 Switching impulse test (type test, routine test)**

951 See clause 14 of IEC 60076-3 and 8.3 of IEC 60076-4.

952 The waveshape obtainable on reactors will be of a damped cosine form, without any saturation
953 effects on the tail, since there is no complete ferro-magnetic circuit through the windings. This
954 waveshape should be characterized mainly by its frequency, determined by the reactor
955 inductance and the generator capacitance, and the damping coefficient. However, practice has
956 been to specify reactor waveshapes as for transformers, that is, by T_1 , T_d and T_z (see figures
957 3b and B.16 in the IEC60076-4).

958 The virtual front time is determined, as for transformers, primarily by the effective winding
959 capacitance, additional load capacitance and the series resistance. It should be long enough
960 to ensure approximately uniform distribution throughout the tested winding, i.e. it must
961 not be below 100 μ sec to avoid too high stress of the first turns of the winding.

962
963 For large values of T_1 , the damping coefficient will be large thus resulting in a relatively short
964 time T_z

965 NOTE Larger T_z can be achieved by testing with impulse generators with high energy content or when using
966 regular impulse generators for transformer testing by an additional capacitance of in the range of 10 nF at
967 the reactor terminal in order to reduce the value of series resistance.

968
969 For small values of T_1 , T_d will become short and the opposite polarity peak may well approach
970 75 % of the test voltage level with an ensuing risk of phase-to-earth or phase-to-phase
971 flashover. Due to these implications, it appears logical, as in the case of transformers, to limit
972 the maximum opposite polarity peak to a safe level, for example 60 %, and to accept the
973 corresponding values of T_1 , T_d and T_z .

974 Normally the transformer characteristic of $T_d \geq 200$ μ s and $T_z \geq 1000$ μ s is not a problem for
975 small reactors (with an inductance $>4,3$ Henry, i.e. <120 Mvar for three-phase 400 kV reactors
976 with relatively high impedances). For larger reactors, i.e. reactors with an inductance below 4,3
977 Henry, T_d and T_z as specified for transformers would require excessive impulse generator
978 extension. For such cases, a minimum value for T_d and T_z should be 120 μ s and 500 μ s
979 respectively to assure adequate volt-time stress.

980 For variable reactors the test shall be carried out in the tap position with the maximum power.

981 For large variable reactor it can be difficult to achieve the standard waveshape in the tap
982 position with the maximum power. In case it can be agreed to use the tap position with the
983 minimum power i.e. with the highest inductance. The turn to turn voltage will be tested with the
984 IVPD test.

985 For low impedance shunt reactors connected to the tertiary winding of transformers (typically
986 air-core dry-type reactors), the achievable wave shape is close to the lightning impulse wave
987 shape. Thus, such reactors are subject to LI or overvoltage turn-to-turn tests only.

988 NOTE In the case of three phase reactors the voltage developed between phases during the switching impulse
989 test will be less than 1,5 times the test voltage. The reactor shall however be designed to withstand 1,5
990 times the test voltage between phases.

991 **7.9.12 Measurement of magnetic characteristic (special test)**

992 Measurement of the magnetic characteristic may be specified when the magnetic characteristic
993 of the reactor is non-linear or saturated (Figure 3.1).

994 For variable reactors this test shall be performed in the tap position with the maximum power.

995 .

996 The linked flux of the reactor windings cannot be measured directly. Therefore an indirect
997 method must be used to establish the magnetic characteristic. The methods of measurement
998 include instantaneous measurements of voltage and current at rated frequency, lower frequency
999 measurements or the DC discharge test method, see Annex C. Alternative methods of
1000 measurement with an equivalent accuracy may also be used.

1001 NOTE In case of reactors without magnetic shield for zero-sequence flux (usually three limb reactors) a single-
1002 phase measurement may not use a flux path representative of the three-phase service condition and this
1003 must be taken into account.

1004

1005 **7.9.13 Measurement of acoustic sound level (routine test, type test)**

1006 The sound level test shall be made generally in accordance with IEC 60076-10. For liquid-
1007 immersed shunt reactors it has to be performed as routine test, while it is a type test for dry-
1008 type shunt reactors.

1009 The sound level measurement shall be executed with the reactor energized at rated voltage
1010 and frequency. For variable reactors this test will be performed in the tap position with the
1011 maximum power.

1012 Because the reactor sound level may vary with temperature, the sound level test shall be carried
1013 out at close to operating temperature. This is most easily achieved by performing the sound
1014 level test at the end of the temperature rise test. With the temperature rise test being a type
1015 test and usually executed for only one unit out of a series of identical units, the remaining units
1016 cannot be tested close to operating temperature. In such a situation, the following procedure
1017 applies: The unit receiving a temperature rise test will be tested twice, in cold condition and
1018 close to operating temperature at the end of the temperature rise test. The observed sound
1019 level difference will then be applied to the remaining units of the series that are tested at
1020 ambient temperature.

1021 The power supply of the shunt reactor for the sound level measurement is usually provided by
1022 a step-up transformer energized at rated reactor voltage while supplying full reactor current at
1023 the same time. This situation often causes a high sound being emitted by the step-up
1024 transformer as it is partly or even fully excited / loaded. Because the step-up transformer is
1025 typically placed in the vicinity to the test object, the emitted sound by the step-up unit may

1026 interfere with the emitted reactor sound. The sound coming from the step-up transformer is part
1027 of the background noise and shall be controlled (minimized) as much as practically possible.

1028 NOTE Mitigation means to minimize the noise impact of the step-up transformer comprise:

- 1029 - increase the distance between step-up transformer and reactor
- 1030 - switch off fans of the step-up transformer during the sound test
- 1031 - arrange sound absorbing panels between step-up transformer and reactor

1032 Because of the high background noise, the sound intensity method is commonly used.

1033 In case the sound level measurement is specified to be executed using the sound pressure
1034 method or in the case where the sound intensity method is not suitable. The following
1035 methodology using the sound pressure method may alternatively be applied. Two separate
1036 sound level measurements along the measurement contour around the disconnected reactor
1037 are performed while the supply transformer is energized:

- 1038 1. at no-load excitation with the reactor test voltage induced at the reactor feeding terminal
- 1039 2. with the reactor feeding terminal short-circuited and reactor test current flowing.

1040 The logarithmic sum of the two measured sound pressure levels establishes an average
1041 background sound pressure level for the reactor measurement contour. It is used to correct the
1042 measured total (combined) sound pressure level with the reactor being energized at test voltage
1043 as per IEC 60076-10. The application of this method is technically justified for a sound level
1044 difference between average background sound pressure level and total (combined) sound
1045 pressure level of 3 dB or more.

1046 In exceptional cases, for example extremely large reactor power and high system voltage, it
1047 may be difficult / not possible to maintain the required test conditions. In this case the test may
1048 be performed at reduced voltage but not less than 0,9 times the rated voltage U_r . It is the
1049 manufacturer's obligation to demonstrate to the user's satisfaction that reduced-voltage testing
1050 produces sufficiently accurate results when extrapolated to the required test voltage. The test
1051 level shall be stated in the tender by the manufacturer and agreed between manufacturer and
1052 purchaser at the time of order.

1053 7.9.14 Measurement of vibration (type test)

1054 7.9.14.1 General

1055 The design and construction of liquid-immersed reactors shall be such as to avoid the
1056 detrimental effects of excessive stress due to vibration. Areas of primary concern in the control
1057 of vibration to ensure proper performance are as follows:

- 1058 • vibration of core and coil assembly;
- 1059 • vibration of tank with associated stresses developed in plates, braces, and welded seams;
- 1060 • vibration of instruments, accessories, and cooling equipment.

1061

1062 7.9.14.2 Test conditions

1063 The reactor under test shall be completely assembled in the service condition with cooling
1064 equipment, gauges, and accessories mounted and connected.

1065 NOTE Where a reactor is equipped with a tank wall mounted noise enclosure, the test may need to be performed
1066 without the enclosure by agreement between purchaser and manufacturer.

1067 The reactor shall be mounted on a level surface that will provide proper support for the base,
1068 in order to eliminate the generation of abnormal tank stresses.

1069 The reactor shall be energized at maximum operating voltage and the rated frequency. Three-
1070 phase excitation is required for three-phase units. When the available test power is insufficient
1071 for testing at maximum operating voltage and/or three-phase excitation, the manufacturer shall
1072 demonstrate to the purchaser that reduced-voltage testing will produce sufficiently accurate
1073 results at the specified conditions. The test should preferably be performed at a stable operating
1074 temperature, but may be done at ambient temperature. In the case of the measurement at
1075 ambient temperature, the measurements should be taken as quick as possible to avoid
1076 temperature changes in the different components of the reactor.

1077 For variable reactors this test will be performed in the tap position with the maximum power.

1078 7.9.14.3 Method of measurement

1079 The vibration of reactor components shall be measured by transducers, optical detectors, or
1080 equivalent measuring devices. The peak-to-peak amplitude of the displacement shall be
1081 determined by direct measurement, or calculated from acceleration or velocity measurements.
1082 The accuracy of the measurement at twice the rated frequency shall be within 10 μm .

1083 Measurements shall be taken on all four sides of the tank wall at a sufficient number of points
1084 evenly distributed over the tank wall to ensure that the maximum value of vibration has been
1085 measured. A suitable method has to be used to scan each tank wall for the maximum vibration
1086 level. This can be done by multiple measuring points, visualization of the vibration with a special
1087 camera or with feeling the area with the fingertips.

1088 Measurements or observations shall be made of the vibration of equipment mounted at the tank.

1089 7.9.14.4 Maximum vibration level

1090 The maximum amplitude of tank wall displacement shall not exceed 200 μm peak-to-peak.
1091 The average amplitude of all measured points shall not exceed 60 μm peak-to-peak.

1092 For the equipment mounted on the tank the manufacturer shall, where reasonable, demonstrate
1093 that the vibrations measured or observed on test have no long-term effects on the stability and
1094 performance of the equipment.

1095 7.9.15 Temperature rise test (type test)

1096 The test shall be made generally in accordance with IEC 60076-2. For dry-type reactors the
1097 temperature class limits as stated in IEC 60076-11 apply.

1098 NOTE During the heat-run on reactors there are two heat sources in tank, The core and the winding. This can
1099 result in a high difference between the average oil in the cooler compared to the average oil of the winding.
1100 For this case it is preferable to use the extrapolation method described in Annex C of IEC 60076-2 with a
1101 linear decrease of the average oil.

1102 This test shall be performed at maximum operating voltage U_{max} and rated frequency.

1103 In exceptional cases, for example extremely large rated power and high system voltage, it may
1104 be difficult to maintain these test conditions. In this case the test may be performed at reduced
1105 voltage but not less than 0,9 times the rated voltage U_r . The test level shall be stated in the
1106 tender by the manufacturer and agreed between manufacturer and purchaser at the time of
1107 order.

1108 The temperature rises shall be corrected to the maximum operating voltage.

1109 Test will be performed in the tap position with the highest losses for a variable reactor.

- 1110 For liquid-immersed reactors the oil temperature rise shall be multiplied by $\left(\frac{U_{\max}}{U_{\text{test}}}\right)^{2 \cdot x}$ and the
- 1111 winding temperature rise above the oil temperature shall be multiplied by $\left(\frac{U_{\max}}{U_{\text{test}}}\right)^y$ with x and y
- 1112 according to the following:
- 1113 • for reactors with ON... cooling $x = 0,8$ $y = 1,6$;
 - 1114 • for reactors with OF... cooling $x = 1,0$ $y = 1,6$;
 - 1115 • for reactors with OD... cooling $x = 1,0$ $y = 2,0$.

1116

1117 NOTE 1 OF and OD cooling would be unusual for a shunt reactor.

1118 NOTE 2 For three-phase reactors with magnetic shield for zero-sequence flux, by agreement between manufacturer
 1119 and purchaser a temperature rise test may be made with d.c. current application to the windings. The oil
 1120 temperature rises are measured at the d.c. current supplying the total corrected losses as determined
 1121 according to 7.9.6.1. AC excitation of a single-phase at maximum voltage $U_{\max}$ is then used to measure the
 1122 winding temperature rise above the oil temperature.

- 1123 For dry-type reactors the winding temperature rise above ambient temperature shall be
- 1124 multiplied by $\left(\frac{U_{\max}}{U_{\text{test}}}\right)^y$ with y according to the following:

- 1125 • for reactors with AN cooling $y = 1,6$;
- 1126 • for reactors with AF cooling $y = 1,8$.

1127 In most cases the total reactor loss at the steady-state condition is somewhat smaller than at
 1128 reference temperature because the ambient temperature is normally lower than the design
 1129 value during the test. This effect shall be neglected. In case of ambient temperatures during
 1130 the test higher than the maximum specified ambient temperature, a correction on the losses to
 1131 the reference temperature can be made.

1132 Care shall be taken in providing appropriate connectors and electrical leads to connect the
 1133 reactor to the power supply during the temperature rise test. This is of particular importance for
 1134 dry-type air-core reactors.

1135 For dry-type air-core reactors if requested, the temperature rise of the reactor terminals shall
 1136 be measured during the reactor temperature rise test. In order to obtain meaningful terminal
 1137 temperature rise measurements, the purchaser shall supply a connector and at least one meter
 1138 of incoming conductor of the type that will be used at site, to the manufacturer for use during
 1139 the temperature rise test. Terminal temperature rise limits shall be as given in clause 6 (see
 1140 also IEC 60943).

1141 7.10 Reactors with auxiliary winding

1142 7.10.1 General

1143 Reactors can be provided with a secondary (low voltage) winding to supply a local auxiliary
 1144 load, for example the 400 V equipment within the substation.

1145 Where a secondary winding is specified this is usually a star-connected winding suitable for
 1146 continuous loading.

1147 7.10.2 Additional tests

1148 The following additional tests on reactors with auxiliary windings shall be performed as a
 1149 minimum:

- 1150 • Measurement of winding resistance on auxiliary winding;
- 1151 • Measurement of voltage ratio and check of phases displacement;
- 1152 • Measurement of short-circuit impedance and load losses;
- 1153 • Applied voltage on auxiliary winding;
- 1154 • Measurement of insulation resistance and/or capacitance and dissipation factor ($\tan \delta$) of
- 1155 the winding insulation to earth;
- 1156 • SFRA as a special test.

1157
1158 In case a separate transformer is used to achieve the nominal voltage, this transformer shall
1159 be tested according to the relevant standard for the transformer, independently from the Shunt
1160 Reactor test.

1161 **7.11 Tolerances**

1162 **7.11.1 Tolerances on reactance at rated voltage and rated frequency**

1163 The tolerance shall be within ± 5 % of rated reactance. For variable reactors this tolerance is
1164 valid for both extreme positions.

1165 In the case of three-phase shunt reactors or banks of three single-phase reactors, the reactance
1166 in the three phases, when connected to a power system of symmetrical voltages, shall not
1167 deviate from the average by more than ± 2 % but always within the above-mentioned ± 5 %
1168 tolerance.

1169 **7.11.2 Tolerances on the linearity of reactance**

1170 For a linear reactor, the measurements of reactance made according to 7.9.5.3 shall be within
1171 ± 5 % of the reactance value measured at rated voltage.

1172 **7.11.3 Tolerance on loss**

1173 The total loss measured and corrected according to 7.9.6 shall not exceed the guaranteed loss
1174 by more than 10 %. Unless otherwise specified, for shunt reactors with tapplings, the tolerances
1175 apply to tap position with the maximum power.

1176

1177

8 Current-limiting reactors and neutral-earthing reactors

8.1 General

This clause describes the requirements for reactors designed to be connected in series with the power system or between the neutral and earth to limit or control the current. These reactors include:

- current-limiting reactors intended to limit the short-circuit or short-time current. During normal operation a continuous current flows through this type of reactor;
- single-phase neutral-earthing reactors for three-phase power systems, connected between the neutral of a power system and earth, for limiting the line-to-earth current under system fault conditions. Neutral-earthing reactors generally carry very little or no continuous current.

Reactors for other current-limiting or controlling purposes, not covered in other clauses of this standard, are covered by this clause. Examples of reactor applications covered by this clause include:

- single-phase neutral-earthing reactors connected between the neutral of shunt reactors and earth which are intended to suppress the arc during single-pole switching of a transmission line. For more information see also Annex A;
- bus tie reactors connected between two different bus sections or power systems to limit fault current transfer;
- motor starting reactors connected in series with an a.c. motor for limiting the starting current;
- power flow control reactors connected in series in a power system to control the power flow;
- arc-furnace series reactors connected in series with an arc-furnace to increase the efficiency of the metal melting operation and reduce voltage variation on the power system;
- insertion reactors momentarily connected across the contacts of a switching device for synchronising and/or for damping switching transients;
- test reactors used in the electrical test circuit of a high power laboratory for adjusting the test current to the required value;
- phase reactors connected in series to a voltage source converter to accommodate the voltage caused by the dissimilar wave shapes at the converter terminals and the a.c. bus (2 level or 3 level converters) or connected as buffer between AC bus and converter (multilevel STATCOM converters).

NOTE 1 Reactors connected in the converter arms of voltage sourced HVDC schemes (VSC HVDC) are considered in clause 13 of this standard.

NOTE 2 Depending on the specific application of such reactors the requirements and tests as per clause 8 of this standard may not fully apply. Any deviation must be agreed between manufacturer and purchaser.

8.2 Design

With regard to design and installation, reactors covered under this clause are classified as:

- single-phase or three-phase;
- dry-type or liquid-immersed type;
- air-core or gapped-core;
- with or without magnetic shield;
- with or without taps;
- for indoor or outdoor installation;
- dry-type with each phase mounted side-by-side or in a vertical stack.

Tap-changers in series reactor applications will face higher stresses. It is recommended that the selection of tap-changers for series reactor applications is made in close cooperation with the OLTC manufacturer. For series reactors in electric arc furnace applications, over load factors beyond 2 are common. For more information see IEC/IEEE 60214-2.

NOTE 1 The magnetic shield of a current-limiting reactor is generally designed to be saturated when the reactor carries a high short-circuit current. This will have the effect of reducing the reactance under short-circuit conditions. The reactor must be designed to meet the rated reactance at rated short-circuit current.

NOTE 2 The magnetic shield of a reactor to be connected to the neutral of a shunt reactor is generally designed not to be saturated up to the rated short-time current. Therefore the reactance is regarded as constant over its operational current range.

8.3 Definitions

8.3.1

rated continuous current I_r

the specified steady-state r.m.s. value of current at rated frequency

8.3.2

rated thermal short-circuit current I_{SCR}

the specified r.m.s. value of the steady-state symmetrical component of the short-circuit current at rated frequency to be carried for the specified duration. This is valid for current-limiting reactors and for neutral-earthing reactors to be connected to the neutral of the power system.

8.3.3

rated thermal short-circuit current duration T_{SCR}

the specified duration of the rated thermal short-circuit current

8.3.4

rated mechanical short-circuit current I_{MSCR}

the specified asymmetrical (peak) fault current. If not specified, the asymmetrical (peak) fault current is derived from the rated thermal short-circuit current.

8.3.5

rated short-time current I_{STr}

For motor-starting and for test reactors: the specified r.m.s. value of the current at rated frequency which is applied for a specified duty-cycle

For neutral-earthing reactors to be connected to the neutral of a shunt reactor: the specified r.m.s. value of the arc-suppression current of the faulted line at rated frequency

8.3.6

rated short-time current duration T_{STr} or duty-cycle

the specified duration of the rated short-time current. The duty-cycle is the specified duration of each application, the interval between applications, and the number of applications of the rated short-time current.

8.3.7

rated inductance L_{SCR}

the specified inductance at rated frequency and at rated thermal short-circuit current I_{SCR} . The rated inductance also includes mutual inductance, if applicable.

1266 **8.3.8**1267 **rated reactance X_{SCR}**

1268 the product of rated inductance and rated frequency multiplied by 2π . The rated reactance is
 1269 expressed in Ohms per phase.

1270 **8.3.9**1271 **mutual reactance X_m of a three-phase reactor**

1272 the ratio between induced voltage in an open phase and the current in an excited phase in
 1273 Ohms per phase at rated continuous current I_r and rated frequency (see also Figure 8.1)

1274 **8.3.10**1275 **coupling factor k**

1276 the mutual reactance expressed in per unit or percent of rated reactance

1277 **8.3.11**1278 **rated short-circuit impedance Z_{SCR}**

1279 the specified impedance per phase at rated frequency and rated thermal short-circuit current
 1280 I_{SCR}

1281 The rated short-circuit impedance is the phasor sum of the rated reactance and the effective
 1282 resistance (derived from the losses) of the reactor. Normally the resistance is much smaller
 1283 than the reactance.

1284 **8.3.11.1**1285 **rated three-phase short-circuit impedance Z_{SCR3}**

1286 the specified impedance per phase at rated frequency and rated three-phase thermal short-
 1287 circuit current I_{SCR} , as an average of the three phases

1288 **8.3.11.2**1289 **rated single-phase short-circuit impedance Z_{SCR1}**

1290 the specified impedance per phase at rated frequency and rated thermal short-circuit current
 1291 I_{SCR} , with the other two phases open-circuit

1292 **8.3.12**1293 **rated short-time impedance Z_{STR}**

1294 the specified impedance per phase at rated frequency and rated short-time current I_{STR}

1295 **8.3.12.1**1296 **rated three-phase short-time impedance Z_{STR3}**

1297 the specified impedance per phase at rated frequency and rated three-phase short-time current
 1298 I_{STR} , as an average of the three phases

1299 **8.3.12.2**1300 **rated single-phase short-time impedance Z_{STR1}**

1301 the specified impedance per phase at rated frequency and rated short-time current I_{STR} with the
 1302 other two phases open-circuit

1303 **8.3.13**1304 **rated continuous impedance Z_r**

1305 the specified impedance per phase at rated frequency and rated continuous current I_r

1306 8.3.13.1**1307 rated three-phase continuous impedance Z_{r3}**

1308 the specified impedance per phase at rated frequency and rated three-phase continuous current
1309 I_r , as an average for the three phases

1310 8.3.13.2**1311 rated single-phase continuous impedance Z_{r1}**

1312 the specified impedance per phase at rated frequency and rated continuous current I_r with the
1313 other two phases open-circuit

1314 8.4 Rating**1315 8.4.1 Rated continuous current**

1316 The rated continuous current I_r shall be specified by the purchaser. For reactors connected in
1317 series in each phase, the rated continuous current may be derived from the system voltage and
1318 throughput power specified by the purchaser.

1319 Unless otherwise specified, for reactors connected in series in each phase, the rated continuous
1320 current is a symmetrical three-phase current.

1321 In the case of neutral-earthing reactors (either to be connected at the neutral of a three-phase
1322 power system or at the neutral of a shunt reactor), a rated continuous current shall be specified
1323 by the purchaser if it is more than 5 % of the rated thermal short-circuit current or the rated
1324 short-time current.

1325 In the case of motor starting reactors, for applications where the reactor is not bypassed after
1326 the motor starting operation, a rated continuous current shall be specified by the purchaser.

1327 8.4.2 Rated thermal short-circuit current

1328 The rated thermal short-circuit current I_{SCr} shall be specified by the purchaser for current-
1329 limiting and neutral-earthing reactors connected to the neutral of a three-phase power system.
1330 It shall be specified by the purchaser as not less than the highest value of symmetrical r.m.s.
1331 current under recognized fault conditions, which may be seen by the reactor in service.
1332 Alternatively the rated thermal short-circuit current may be derived from the specified system
1333 short-circuit power, system voltage and reactor impedance.

1334 8.4.3 Rated thermal short-circuit current duration

1335 The rated thermal short-circuit current duration T_{SCr} , where applicable, shall either be specified
1336 by the purchaser or otherwise the standard values as indicated below shall be used:

1337 for current-limiting reactors 2 s.

1338 NOTE 1 The duration selected should reflect the cumulative thermal effects of the utilities auto re-closure philosophy
1339 and the time a fault is allowed to exist before it is interrupted.

1340 NOTE 2 The duration of thermal short-circuit current can impact the cost of the reactor where the short-circuit current
1341 exceeds about twenty-five times the rated continuous current.

1342 for neutral-earthing reactors connected to the neutral of a power system 10 s.

1343 NOTE If several successive faults may occur within a short period of time, the duration, the interval of time between
1344 applications, and the number of applications shall be specified by the purchaser. The rated thermal short-
1345 circuit current duration shall be selected accordingly.

8.4.4 Rated mechanical short-circuit current

The specified rated mechanical short-circuit current I_{MSCr} depends on the X/R ratio of the system and shall be calculated as per 4.2.3 of IEC 60076-5. If the system impedance and X/R ratio are not specified by the purchaser, the rated mechanical short-circuit current shall be taken to be a value equal to $1,8 \cdot \sqrt{2}$ times the rated thermal short-circuit current value ($I_{MSCr} = 2,55 \cdot I_{SCr}$).

8.4.5 Rated short-time current

The rated short-time current I_{STr} shall be specified, where applicable, by the purchaser along with the associated rated short-time current duration, T_{STr} or duty-cycle.

For neutral-earthing reactors to be connected at the neutral of a shunt reactor, this current is the arc-suppression current of the faulty line following single-pole switching.

NOTE A rated short-time current can be specified for any type of reactor that is intended for applications where the current will be applied repetitively.

8.4.6 Rated short-time current duration or duty-cycle

The rated short-time current duration T_{STr} or duty-cycle shall be specified by the purchaser, where applicable. For example, it may be associated with motor starting operations or test circuit duty where a prescribed cycle of short-time current and zero current conditions is specified. Subsequent to the starting/test cycle, the reactor may carry rated continuous current or be removed from service.

All information regarding the short-time current duty-cycle shall be provided in the reactor specification, including, where applicable, the maximum magnitude and duration of short-time current, minimum duration between successive short-time current applications, the level of current between short-time current applications and the maximum number of consecutive applications of short-time current of the specified duration.

NOTE Several different duty-cycles may be specified for different operating conditions, for example for cold and warm starting of motors.

For neutral-earthing reactors to be connected to the neutral of a shunt reactor, the rated short-time current duration shall be specified by the purchaser. It is related to the time between the appearance of the fault and either the successful re-closing of the faulted phase or the disconnection of all three phases.

8.4.7 Coupling factor

Where the purchaser requires that the rated single-phase short-circuit impedance is to be approximately equal to the three-phase short-circuit impedance, the maximum allowable coupling factor shall be specified in the enquiry.

For a three-phase reactor, or a bank of separate single-phase reactors with defined installation, the manufacturer shall, on request, supply information on the coupling factors or mutual reactances between phases (see Annex D for details).

8.4.8 Rated short-circuit impedance

The rated short-circuit impedance Z_{SCr} shall be specified by the purchaser. Alternatively, the purchaser may specify the system short-circuit current or power and the desired thermal short-circuit current. The rated short-circuit impedance shall be derived from these values.

1387 In the case of reactors that do not have a thermal short-circuit current rating, rated impedances
1388 shall be specified at the rated short-time current I_{STr} (see 8.4.9) and/or at the rated continuous
1389 current I_r (see 8.4.10), as applicable.

1390 **8.4.8.1 Reactors with a coupling factor less than 5 %**

1391 In the case of three-phase reactors where the coupling factor is less than 5 %, only the rated
1392 three-phase short-circuit impedance Z_{SCr3} as defined in 8.3.11.1 needs to be specified.

1393 **8.4.8.2 Reactors with a coupling factor of 5 % or more**

1394 If the coupling factor is 5 % or more (this will normally be the case for three-phase vertically
1395 stacked reactors), two different impedances shall be recognised: The rated three-phase short-
1396 circuit impedance Z_{SCr3} and the rated single-phase short-circuit impedance Z_{SCr1} .

1397 The duty on three-phase current-limiting reactors is dependent on system earthing. If there is
1398 high impedance system earthing, the duty on reactors connected in series in each phase is to
1399 limit symmetrical three-phase fault currents. In this case, only Z_{SCr3} shall be specified.

1400 If the power system is effectively earthed, both single-phase and three-phase system fault
1401 currents are to be evaluated, and both Z_{SCr3} and Z_{SCr1} shall be considered. One or both of
1402 these impedances shall be specified and the measured values provided upon request. If only
1403 one impedance value is specified, it is understood that both Z_{SCr3} and Z_{SCr1} shall meet the
1404 specified impedance value within the tolerances identified in 8.10. It must be kept in mind that
1405 in some cases, such as where the reactors are mounted in vertical stacked arrangements and
1406 coupling factors of adjacent units are significant, reactor impedance during a single-phase fault
1407 may be significantly different than during a three-phase fault.

1408 Generally, for the three-phase reactor applications dealt with in this clause, each phase reactor
1409 is designed to have the same self-inductance. However, where it is desirable to vertically stack
1410 reactors and also maintain three equal current magnitudes during three-phase fault conditions,
1411 the purchaser shall specify this and the reactors shall be compensated for mutual inductance.
1412 In this case the self-inductance of each phase reactor is uniquely adjusted. Therefore, the self-
1413 inductance of each phase reactor will not be the same as that of the other phases and the
1414 effective phase impedance during a single-phase fault will be lower than that for a three-phase
1415 fault. For more information see Annex D.

1416 **8.4.9 Rated short-time impedance**

1417 A short-time impedance Z_{STr} together with the rated short-time current I_{STr} , and the rated short-
1418 time current duration T_{STr} or duty-cycle shall be specified by the purchaser, where applicable.

1419 The reactor shall be a linear reactor for all currents up to and including the rated short-time
1420 current I_{STr} .

1421 In the case of three-phase reactors where the coupling factor is less than 5 %, only the rated
1422 three-phase short-time impedance shall be specified.

1423 If the coupling factor is 5 % or more (this will normally be the case for three-phase vertically
1424 stacked reactors), two different impedances shall be recognised: The rated three-phase short-
1425 time impedance Z_{STr3} and the rated single-phase short-time impedance Z_{STr1} . One or both of
1426 these impedances shall be specified and the measured values provided upon request (see also
1427 8.4.8.2).

1428 8.4.10 Rated continuous impedance

1429 In the case of air-core reactors, the rated continuous impedance Z_r , rated short-time impedance
1430 Z_{STr} , and the rated short-circuit impedance Z_{SCr} , are identical.

1431 In the case of three-phase reactors where the coupling factor is less than 5 %, only the rated
1432 three-phase short-time impedance shall be specified.

1433 If the coupling factor is 5 % or more (this will normally be the case for three-phase vertically
1434 stacked reactors), two different impedances shall be recognised: The rated three-phase
1435 continuous impedance Z_{r3} and the rated single-phase continuous impedance Z_{r1} . One or both
1436 of these impedances shall be specified and the measured values provided upon request (see
1437 also 8.4.8.2).

1438 For gapped-core reactors and magnetically-shielded air-core reactors, the rated continuous
1439 impedance Z_r , will be greater than the rated short-circuit impedance Z_{SCr} and rated short-time
1440 impedance Z_{STr} .

1441 In this case the purchaser may specify a maximum value for the rated continuous impedance
1442 where this is important for voltage control or other reasons. The reactor shall be a linear reactor
1443 for all currents up to and including the rated continuous current I_r .

1444 8.5 Ability to withstand rated thermal and rated mechanical short-circuit current

1445 Current-limiting reactors and neutral-earthing reactors to be connected to the neutral of the
1446 power system shall be designed to withstand the thermal and dynamic effects of the rated short-
1447 circuit current including the associated electrical stress for its rated duration. Unless otherwise
1448 specified by the purchaser, the interval between fault conditions totalling the rated duration is
1449 at least six hours. If the expected frequency of short-circuit application is more than
1450 approximately ten times per year on average, this shall be specified by the purchaser.

1451 8.6 Temperature rise**1452 8.6.1 Temperature rise at rated continuous current**

1453 The temperature rise limits given in IEC 60076-2 or IEC 60076-1 or IEC 60076-11 respectively
1454 apply. Reactors connected in series in the power system shall be designed for loading and
1455 overload according to the guidelines set out in IEC 60076-7 for liquid-immersed and IEC 60076-
1456 12 for dry-type reactors.

**1457 8.6.2 Temperature due to rated thermal short-circuit current and rated short-time
1458 current loading**

1459 The calculated temperature of the winding after rated thermal short-circuit current I_{SCr} or rated
1460 short-time current I_{STr} loading shall not exceed the values prescribed for transformer windings
1461 under short-circuit conditions given in 4.1.4 of IEC 60076-5.

1462 8.7 Insulation level**1463 8.7.1 General**

1464 For specification of the insulation level see IEC 60076-3.

1465 8.7.1.1 Insulation requirements for current-limiting reactors

1466 The insulation requirements between phases and to earth shall generally correspond to the
1467 highest voltage of equipment U_m . The insulation requirements across the winding may be
1468 specified to be lower, particularly if surge arresters are connected in parallel with the winding.

1469 It is recommended that the rated voltage of the parallel connected surge arrester is selected to
1470 be not less than 1,2 times the voltage developed across the reactor by the rated thermal short-
1471 circuit current.

1472 NOTE The manufacturer shall ensure the reactor is designed to withstand the voltages experienced across the
1473 winding during short-circuit conditions.

1474 If the reactor is to be installed with a by-pass arrangement which may be closed when the
1475 reactor is energized this shall be stated by the purchaser and a double-ended lightning impulse
1476 test should be specified.

1477 8.7.1.2 Insulation requirements for neutral-earthing reactors

1478 The insulation requirements shall correspond to the insulation of the neutral of the power system
1479 or the shunt reactor in which the reactor is to be installed. For the earth terminal, the selection
1480 of a reduced insulation level may be appropriate (non-uniform insulation).

1481 8.8 Rating plates

1482 Each reactor shall be provided with a rating plate of weatherproof material, fitted in a visible
1483 position, showing in all cases the appropriate items indicated below. The entries on the plate
1484 shall be indelibly marked (for example by etching, engraving or stamping).

- 1485 • Type of reactor;
- 1486 • Outdoor/indoor application;
- 1487 • Number of this standard;
- 1488 • Manufacturer's name;
- 1489 • Manufacturer's serial number;
- 1490 • Year of manufacture;
- 1491 • Insulation level(s);
- 1492 • Number of phases;
- 1493 • Rated frequency;
- 1494 • Highest voltage for equipment;
- 1495 • Rated continuous current (where applicable);
- 1496 • Rated thermal short-circuit current and duration (where applicable);
- 1497 • Rated mechanical short-circuit current (where applicable);
- 1498 • Rated short-time current and duration or duty-cycle (where applicable);
- 1499 • Impedance at rated continuous current at single-phase and at three-phase excitation,
1500 measured values (where applicable);
- 1501 • Impedance at rated short-circuit current, calculated or measured value (for gapped-core
1502 reactors and magnetically-shielded air-core reactors);
- 1503 • Impedance at rated short-time current, calculated or measured value (for reactors where
1504 short-time current is specified);
- 1505 • Type of cooling;
- 1506 • Thermal class of insulation (for dry-type reactors only);
- 1507 • Temperature (see shunt reactors)
- 1508 • Total mass;
- 1509 • Transportation mass (for liquid-immersed reactors);
- 1510 • Untanking mass (for liquid-immersed reactors);
- 1511 • Mass of insulating liquid (where applicable);

- 1512 • Type of insulating liquid, if not mineral oil (where applicable);
- 1513 • Insulation level of the earth terminal of the winding for neutral-earthing reactors with non-
- 1514 uniform insulation;
- 1515 • Connection diagram showing tapplings and instrument transformers (where applicable);
- 1516 • Type of tap changer (where applicable).

1517 **8.9 Tests**

1518 **8.9.1 General**

1519 The general requirements for routine, type and special tests shall be as prescribed in
1520 IEC 60076-1.

1521 **8.9.2 Routine tests**

1522 The following routine tests shall be performed:

- 1523 • measurement of winding resistance (IEC 60076-1);
- 1524 • measurement of impedance at rated continuous current (8.9.5);
- 1525 • measurement of impedance at rated short-time current for neutral-earthing reactors to be
- 1526 connected to the neutral of a shunt reactor, starter reactors and test reactors (8.9.6);
- 1527 • measurement of loss at ambient temperature (8.9.7);
- 1528 • separate source AC withstand voltage test for liquid-immersed reactors (8.9.8);
- 1529 • winding overvoltage test for current-limiting reactors (8.9.9);
- 1530 • winding overvoltage test for neutral-earthing reactors (8.9.10);
- 1531 • measurement of insulation resistance and/or capacitance and dissipation factor ($\tan \delta$) of
- 1532 the winding insulation to earth for liquid-immersed reactors. (These are reference values for
- 1533 comparison with later measurements in the field. No limitations for the values are given
- 1534 here.);
- 1535 • leak testing with pressure for liquid-immersed reactors (tightness test);
- 1536 • check of magnetic shield and/or frame insulation for liquid immersed reactors with magnetic
- 1537 shield or frame insulation.

1538

1539 **8.9.3 Type tests**

1540 The following type tests shall be performed:

- 1541 • temperature rise test at rated continuous current (8.9.11);
- 1542 • lightning impulse test for current-limiting reactors (8.9.12);
- 1543 • measurement of power consumption of fans and oil pumps, if any.

1544

1545 **8.9.4 Special tests**

1546 The following special tests shall be performed when specifically requested by the purchaser:

- 1547 • short-circuit test for current-limiting reactors, neutral-earthing reactors to be connected to a
- 1548 neutral of a power system and for test reactors (8.9.13);
- 1549 • measurement of reactance of the winding in the case of gapped-core and magnetically-
- 1550 shielded air-core reactors (8.9.21);
- 1551 • measurement of acoustic sound level (8.9.14);

- 1552 • separate source AC withstand voltage test for dry-type reactors mounted on special support
- 1553 insulators or insulated to ground by other means (8.9.8);
- 1554 • measurement of loss close to reference temperature in the case of liquid-immersed reactors
- 1555 (8.9.7);
- 1556 • measurement of vibration at rated continuous current for liquid-immersed reactors (8.9.15);
- 1557 • switching impulse test (8.9.16);
- 1558 • double-ended lightning impulse test (8.9.17);
- 1559 • measurement of coupling factor (8.9.18);
- 1560 • wet winding overvoltage test (8.9.19);
- 1561 • wet separate source AC withstand voltage test for outdoor dry-type reactors mounted on
- 1562 special support insulators or insulated to ground by other means (8.9.20);
- 1563 • vacuum deflection test on liquid immersed reactors;
- 1564 • pressure deflection test on liquid immersed reactors;
- 1565 • vacuum tightness test on site on liquid immersed reactors;
- 1566 • measurement of frequency response (Frequency Response Analysis or FRA);
- 1567 • check of external coating (ISO 2178 and ISO 2409 or as specified);
- 1568 • mechanical test or assessment of tank for suitability for transport (to customer
- 1569 specification).

1570

1571 **8.9.5 Measurement of impedance at rated continuous current (routine test)**

1572 The impedance shall be measured at rated frequency.

1573 For air-core reactors, the measurements may be made at any current up to rated continuous
1574 current.

1575 For gapped-core reactors and magnetically-shielded air-core reactors, the measurements shall
1576 be made at rated continuous current where a rated continuous current has been specified. If
1577 not specified, the highest available (practicable) continuous current to be used for test shall be
1578 agreed upon by the manufacturer and purchaser at the tender stage.

1579 For three-phase reactors where the coupling factor between phases exceeds 5 %, the current
1580 in each phase shall be measured while applying a system of symmetrical three-phase voltages
1581 to the star-connected phase windings.

1582 The impedance shall be taken as

$$1583 \quad \frac{\text{line – to – line applied voltage}}{\text{average measured line current} \cdot \sqrt{3}}$$

1584 **equation 2**

1585 For three-phase reactors with coupling factors greater than 5 %, the mutual reactance between
1586 each pair of phases shall be measured and their polarities shall be checked. For the method of
1587 measurement see Figure 8.1. In the event that it is not possible to totally shield connecting
1588 leads from one another in order to prevent induced voltages, a more rigorous determination of
1589 mutual reactance can be obtained by measuring the reactance of each single-phase coil and of
1590 each pair of phase coils connected in series. The mutual reactance can be derived from the
1591 measured results by calculation.