

Power transformers —

Part 6: Reactors

ICS 29.180

National foreword

This British Standard is the UK implementation of EN 60076-6:2008. It is identical to IEC 60076-6:2007. It supersedes BS EN 60289:1995, which will be withdrawn on 1 June 2011.

The UK participation in its preparation was entrusted to Technical Committee PEL/14, Power transformers.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Part 6: Reactors
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(IEC 60076-6:2007)

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Foreword

The text of document 14/538/CDV, future edition 1 of IEC 60076-6, prepared by IEC TC 14, Power transformers, was submitted to the IEC-CENELEC Parallel Unique Acceptance Procedure and was approved by CENELEC as EN 60076-6 on 2008-06-01.

This European Standard supersedes EN 60289:1994 + A11:2002.

EN 60076-6:2008 includes the following significant technical changes with respect to EN 60289:1994:

- wide extension of the “Definitions”, “Rating” and “Tests” clauses,
- more consequent distinction between definition and rating,
- “Tests” subclauses take into account the latest revisions of relevant EN 60076 standards,
- dielectric testing of reactors is now in line with dielectric testing of transformer according to EN 60076-3:2001,
- consequent distinction between oil-immersed and dry-type reactor,
- document offers an easier handling and is a more stand-alone document than EN 60289,
- introduction of the discharge reactor as part of Clause 9,
- introduction of the turn-to-turn overvoltage test for dry-type reactors (Annex E),
- important background information given by newly introduced informative annexes,
 - Annex A (informative) – Information on shunt reactor switching and on special applications
 - Annex B (informative) – Magnetic characteristic of reactors
 - Annex C (informative) – Mutual reactance, coupling factor and equivalent reactances of three-phase reactors
 - Annex D (informative) – Temperature correction of losses for liquid-immersed gapped-core and magnetically shielded air-core reactors
 - Annex F (informative) – Short-circuit testing
 - Annex G (informative) – Resistors – Characteristics, specification and tests.

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Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60076-6:2007 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60143	NOTE Harmonized in EN 60143 series (not modified).
IEC 60168	NOTE Harmonized as EN 60168:1994 (not modified) + A1:1997 (not modified) + A2:2000 (not modified).
IEC 60273	NOTE Harmonized as HD 578 S1:1992 (not modified).
IEC 60529	NOTE Harmonized as EN 60529:1991 (not modified).
IEC 60871-1	NOTE Harmonized as EN 60871-1:2005 (not modified).
IEC 61378-1	NOTE Harmonized as EN 61378-1:1998 (not modified).
IEC 61378-2	NOTE Harmonized as EN 61378-2:2001 (not modified).
IEC 62271-110	NOTE Harmonized as EN 62271-110:2005 (not modified).

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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 reactor 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 part of IEC 60076.

Clauses 1 to 6 form the general parts of the document, which apply to all types of reactor. Clauses 7 to 12 deal individually with each different type of reactor. Generally, only one of the Clauses 7 to 12 will apply to a specific reactor.

This part of IEC 60076 has more than one definition Subclause. The general definitions given in Clause 3 apply to the whole document. Each of the Clauses 7 to 12 dealing with a certain type of reactor includes a definition Subclause relevant and applying only to that Clause.

Clauses 7 to 12 have been given a uniform structure. Within this structure, the Rating Subclause sets out the minimum information that a purchaser shall supply with the reactor specification. The test Subclause in each Clause defines the relevant tests that can be applied to that particular type of reactor and may include some additional items that shall be agreed on at the time of order.

Annexes A, B, C, D, F and G provide further information for certain reactor applications and testing. Annex E describes the dielectric turn-to-turn test.

This part of IEC 60076 covers both dry-type and liquid-immersed reactors and where Clauses or Subclauses apply to only one type this is made clear.

Where possible, the requirements of this part of IEC 60076 have been harmonised with the equivalent IEEE standard.

POWER TRANSFORMERS –

Part 6: Reactors

1 Scope

This part of IEC 60076 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 application;

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 part of IEC 60076 may be applicable as a whole or in part.

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 60060-1:1989, *High-Voltage test techniques – Part 1: General definitions and test requirements*

IEC 60076-1:1993, *Power transformers – Part 1: General*
Amendment 1 (1999)

IEC 60076-2:1997, *Power transformers – Part 2: Temperature rise*

IEC 60076-3:2000, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-4:2002, *Power transformers – Part 4: Guide to lightning impulse and switching impulse testing – Power transformers and reactors*

IEC 60076-5:2006, *Power transformers – Part 5: Ability to withstand short-circuit*

IEC 60076-7:2005, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60076-8:1997, *Power transformers – Part 8: Application guide*

IEC 60076-10:2005, *Power transformers – Part 10: Determination of sound levels*

IEC 60076-11:2004, *Power transformers – Part 11: Dry-type transformers*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 60721-2-6, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature. Earthquake vibration and shock*

IEC 60815, *Guide for the selection of insulators in respect of polluted conditions*

IEC 60905:1987, *Loading guide for dry-type power transformers*

IEC 60943:1998, *Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals*

3 Terms and definitions

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

The definitions given in this Clause are of a general nature. Additional definitions are given in those Clauses of this part of IEC 60076 which are specific to a particular type of reactor or which are given a particular meaning when related to that type of reactor.

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

3.1 Types of reactor

3.1.1

shunt reactor

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

3.1.2

current-limiting reactor

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

3.1.3

neutral-earthing reactor

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

3.1.4**power flow control reactor**

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

3.1.5**motor starting reactor**

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

3.1.6**arc-furnace series reactor**

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

3.1.7**damping reactor**

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

3.1.8**filter reactor**

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

3.1.9**discharge reactor**

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

3.1.10**earthing transformer (neutral coupler)**

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.

3.1.11**arc-suppression reactor**

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)

3.1.12**smoothing reactor**

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

3.2 Other definitions**3.2.1****highest voltage for equipment**

U_m

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

3.2.2**magnetic shield**

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

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

3.2.3

air-core reactor

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

3.2.4

gapped-core reactor

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

3.2.5

magnetically-shielded air-core reactor

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

3.2.6

air-core reactance of a gapped-core or magnetically-shielded air-core reactor

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

3.2.7

magnetic characteristic

the magnetic characteristic of a reactor is the relationship of the linked flux of the reactor winding versus current (see Figure 1 and Figure 2).

NOTE The magnetic characteristic may be linear as shown in Figure 1a, non-linear as shown in Figure 1b or saturated as shown in Figure 1c.

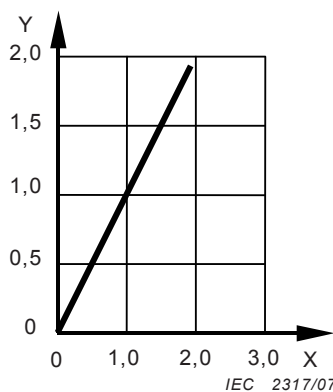


Figure 1a – Linear

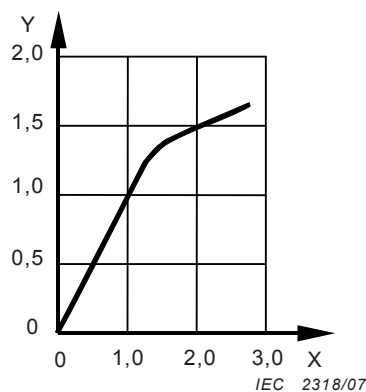


Figure 1b – Non-linear

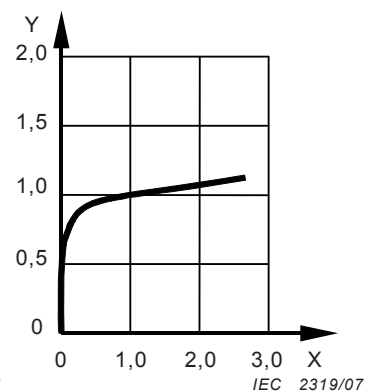


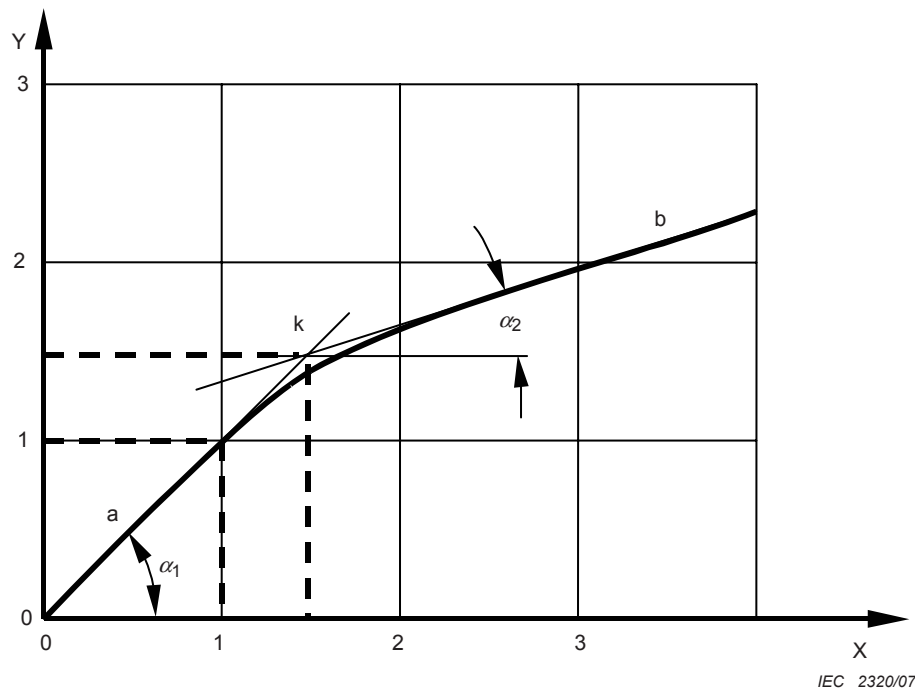
Figure 1c – Saturated

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.

Figure 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.

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.

Figure 2 – Parameters for non-linear magnetic characteristic

3.2.8 linear reactor

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 Figure 1a if there is no ferromagnetic component, or a non-linear magnetic characteristic as shown in Figure 1b if the design incorporates a ferromagnetic core or shield.

3.2.9 saturated reactor

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 Figure 1c.

3.2.10 power frequency

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

3.2.11 reference temperature

for liquid-immersed reactors, the reference temperature is 75 °C; 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 upon.

4 Symbols and abbreviations

Symbol	Meaning	Units
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
I_{equ}	Equivalent current at power frequency	A
I_d	Rated continuous direct current	A
I_h	Harmonic current of the h^{th} harmonic	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_{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_{STr}	Rated short-time current	A
k	Coupling factor (see NOTE)	
L_{inc}	Incremental inductance	H
L_r, L_{SCr}	Rated inductance (see NOTE)	H
Q_f	Quality factor	
R	d.c. resistance	Ω
T_{NSTr}	Rated short-time neutral current duration	s
T_r	Rated current duration	s
T_{SCr}	Rated thermal short-circuit current duration	s
T_{STr}	Rated short-time current duration	s
U_{ac}	AC withstand voltage	V
U_d	Rated d.c. voltage	V
U_{dc}	DC withstand voltage	V
U_{dmax}	Highest continuous d.c. voltage	V
U_m	Highest voltage for equipment (see IEC 60076-3:2000, 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
X_0	Zero-sequence reactance	Ω
X_m	Mutual reactance	Ω
X_r, X_{SCr}	Rated reactance (see NOTE)	Ω
Z_0	Zero-sequence impedance	Ω
Z_r	Rated continuous impedance	Ω

Symbol	Meaning	Units
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
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 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 IEC 60721-2-6, subject to agreement between manufacturer and purchaser.

6 Design, testing, tolerances and application

The application of tests to reactors generally follows the corresponding rules for transformers in IEC 60076, but there may be special factors applicable to certain reactors, set out in this part of IEC 60076, 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.

Under some circumstances, the use of a test winding with a test core can be appropriate in order to achieve the full test levels.

The tests shall be carried out with the reactor erected substantially as in service, as far as features affecting the test results are concerned. Clause 10.1 of IEC 60076-1:1993 applies, however dry-type reactors may be tested at any ambient temperature.

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

As the power factor of reactors is normally very low, the measurement of loss using analog wattmeters may be subject to considerable errors. The measurement of loss using flux compensated current transformers, standard capacitors as voltage transducers and digital wattmeters may provide the required accuracy. A suitable bridge method may also provide the required accuracy. For more information see Clause 10 of IEC 60076-8:1997. At the purchaser's request, satisfactory documentation regarding the accuracy of the proposed method shall be provided.

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

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

The temperature, at specified maximum ambient temperature, of the winding terminals of dry-type reactors shall not exceed the limits given in Table 1.

Table 1 – 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

For more information see IEC 60943.

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

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.

NOTE Information on special applications is given in Annex A.

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;
- for fixed or variable reactance;
- linear or saturated.

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 B.

7.3 Terms and definitions

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

7.3.1

rated voltage

U_r

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

$U_{\max}$

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 3.2.1) but in particular cases, it may have the same value.

7.3.3

rated power

reactive power of the shunt reactor specified for operation at rated voltage and rated frequency. See also note in 7.4.3.

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 turns.

7.3.4

rated current

I_r

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.

7.3.5

rated reactance (rated inductance)

$X_r (L_r)$

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.

7.3.6

zero-sequence reactance of a three-phase star-connected reactor

X_0

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 C.

7.3.7

mutual reactance of a three-phase reactor

X_m

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.

7.3.8

inrush current level

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 7.8. 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.

NOTE Where three single-phase reactors are supplied for connection as a three-phase bank, the rated power is normally quoted as the power of a single-phase reactor. If three-phase power is specified, this shall be clearly stated.

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 upon between purchaser and manufacturer at the time of order.

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

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 C.

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 Clause B.6.

7.4.7 Linearity of the shunt reactor

Unless otherwise specified, the reactor shall be a linear reactor within the tolerance given in 7.9.3 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 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 part of IEC 60076;
- 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;
- type of cooling;
- thermal class of insulation (for dry-type reactors only);
- temperature rise of top-oil and average winding (for liquid-immersed reactors only);
- total mass;
- transportation mass (for liquid-immersed reactors);
- untanking mass (for liquid-immersed reactors);
- mass of insulating liquid (where applicable);
- type of insulating liquid, if not mineral oil (where applicable);
- connection diagram showing tappings and instrument transformers (where applicable);
- type of tap changer (where applicable);
- zero-sequence reactance, measured value (where applicable on request);
- mutual reactance, measured value (where applicable on request).

7.8 Tests

7.8.1 General

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

7.8.2 Routine tests

The following routine tests shall be performed:

- measurement of winding resistance (IEC 60076-1);

- measurement of reactance (7.8.5);
- measurement of loss at ambient temperature (7.8.6);
- dielectric tests (7.8.10);
- measurement of insulation resistance and/or capacitance and dissipation factor ($\tan \delta$) of the winding insulation to earth for liquid-immersed reactors. (These are reference values for comparison with later measurements in the field. No limitations for the values are given here.)

7.8.3 Type tests

The following type tests shall be performed:

- temperature rise test (7.8.14);
- measurement of vibration for liquid-immersed reactors (7.8.13);
- measurement of acoustic sound level (7.8.12);
- dielectric tests (7.8.10);
- measurement of power consumption of fans and oil pumps, if any.

7.8.4 Special tests

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

- measurement of zero-sequence reactance on three-phase reactors (7.8.8);
- measurement of mutual reactance on three-phase reactors (7.8.9);
- measurement of harmonics of the current (7.8.7);
- measurement of loss close to reference temperature in the case of liquid-immersed reactors (7.8.6);
- determination of linearity of reactance (7.8.5.3);
- measurement of magnetic characteristic for gapped-core reactors and magnetically-shielded air-core reactors (7.8.11);
- dielectric tests (7.8.10);
- measurement of acoustic sound level close to service temperature (7.8.12).

7.8.5 Determination of reactance and linearity of reactance

7.8.5.1 Method

- The reactance shall be determined at rated frequency by applying an approximately sinusoidal voltage.
- 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.
- 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
$$\frac{\text{line – to – line applied voltage}}{\text{average measured line current} \times \sqrt{3}}$$

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 should be made and a suitable correction factor agreed upon.

7.8.5.2 Measurement of reactance at rated voltage (routine test)

The measurement of the reactance shall be made according to 7.8.5.1 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.

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 $0,9 U_r$. In this case, the reactor shall be shown to be a linear reactor according to 7.8.5.3. If the manufacturer is not able to measure at U_r , then the achievable test level shall be stated in the tender.

7.8.5.3 Determination of linearity of reactance (special test)

The reactance shall be measured with the method as described in 7.8.5.1 at $\leq 0,7 U_r$, $0,9 U_r$, 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.

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 7.8.11 and the reactance calculated.

NOTE For more information, see also Annex B.

7.8.6 Measurement of loss (routine test, special test)

7.8.6.1 General

Losses are based on reactor operation with rated current at rated frequency and at reference temperature. Measured losses shall be corrected to rated current and reference temperature.

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.

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.

7.8.6.2 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 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 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 when supplied by the manufacturer of the reactor shall be in place during the test and other metal parts shall be avoided.

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 any convenient ambient temperature and corrected to reference temperature according to the method given in IEC 60076-1.

7.8.6.3 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 the 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 $0,9 U_r$.

The total loss is composed of ohmic loss, iron loss and additional loss. The ohmic loss portion is taken to be equal to $I_r^2 R$, R being the measured d.c. resistance, I_r being the rated current. Iron loss and additional loss cannot be separated by measurement. The sum of iron loss and additional loss is therefore the difference between the total loss and the ohmic 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 is corrected to reference temperature according to the method given in IEC 60076-1. A correction of iron loss and additional loss to reference temperature is not normally practical. Therefore, iron loss and additional loss shall be deemed independent of temperature. This assumption normally gives a slightly higher loss figure at the reference temperature than actually exists.

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

NOTE Annex D gives an example of temperature correction of losses.

7.8.7 Measurement of harmonics of the current (special test)

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

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

NOTE 1 Unless the purchaser has particular harmonic current requirements, this test is not normally performed on linear shunt reactors.

NOTE 2 This measurement is practicable only if the distortion factor (see Clause B.5) of the applied voltage is less than 2 %.

7.8.8 Measurement of zero-sequence reactance on three-phase reactors (special test)

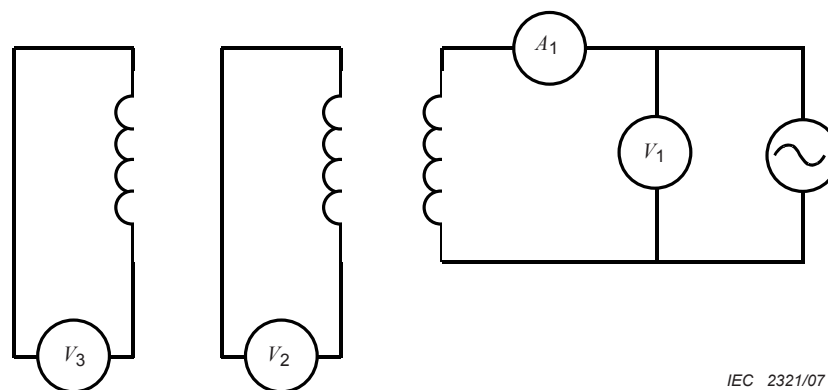
See IEC 60076-1.

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

7.8.9 Measurement of mutual reactance on three-phase reactors (special test)

Unless otherwise specified, the measurement shall be made at rated voltage according to Figure 3 for gapped-core reactors and magnetically-shielded air-core reactors. For other reactors, any convenient voltage may be used for this measurement.

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



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Key

V_1 , V_2 , V_3 : voltmeter reading

A_1 : ammeter reading

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

Figure 3 – Measurement of mutual reactance for three-phase reactors or banks of three single-phase reactors

7.8.10 Dielectric tests

7.8.10.1 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.

7.8.10.2 Separate source a.c. withstand voltage test (routine test, special test)

This test applies as a routine test for liquid-immersed reactors. See Clause 11 of IEC 60076-3:2000.

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 60168.

7.8.10.3 Induced a.c. withstand voltage test (routine test)

Test voltages U_1 and U_2 and the relevant test methods as specified in IEC 60076-3 shall be agreed upon between manufacturer and purchaser at the time of the order.

The induced a.c. withstand 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.

Exceptionally, the required test level according to IEC 60076-3 for the induced a.c. withstand 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 a.c. withstand voltage test may be performed at lower levels and the dielectric withstand capability of the reactor tested by additional lightning impulse tests for reactors with $U_m < 170$ kV and 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 60076-3:2000, 12.2.1 (short-duration a.c. withstand voltage test).

Reactors with $72,5$ kV $< U_m \leq 170$ kV and uniform insulation shall be tested according to IEC 60076-3:2000, 12.2.2 (short-duration a.c. withstand voltage test). Single-phase reactors shall be tested with the test level U_1 equal to two times the rated voltage across the winding.

If the power and voltage requirements for the test level U_1 exceeds those available at the test station this shall be stated by the manufacturer in the tender. In this case, the test level U_1 may be reduced or omitted and the test duration extended by agreement between purchaser and manufacturer.

Reactors with $72,5$ kV $< U_m \leq 170$ kV and non-uniform insulation shall be tested according to IEC 60076-3:2000, 12.3 a) and 12.3 b) (short-duration a.c. withstand voltage test). The excitation circuit applicable for all types of reactor design for the phase-to-earth test according 12.3 a) is given in Figure 4. In this case, the neutral will be subjected to a voltage of $1/3 U_{\text{test}}$. In the special case of a reactor design with a magnetic shield for zero-sequence flux, the test circuit given in Figure 6, may also be used. In this case, there is no voltage stress on the neutral.

By agreement between manufacturer and purchaser, the three-phase test 12.3 b) of IEC 60076-3:2000 may be replaced by three single-phase tests as shown in Figure 5. In this case the test level U_1 is equal to $2 U_r/\sqrt{3}$.

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

For single-phase reactors, only test 12.3 a) of IEC 60076-3:2000 applies. The neutral is normally earthed during this test. Alternatively, the voltage at the neutral terminal may be raised by connection to an auxiliary booster transformer to limit the test voltage across the winding to two times the rated voltage across the winding. In such cases, the neutral shall be insulated accordingly.

If the power and voltage requirement for these tests exceeds those available at the test station, this shall be stated by the manufacturer in the tender. In this case, only the test 12.3 b) of IEC 60076-3:2000 may be performed with the test level U_1 being reduced or omitted and the test duration extended by agreement between manufacturer and purchaser.

Reactors with $U_m > 170$ kV and non-uniform insulation shall be tested according to IEC 60076-3:2000, 12.4 (long-duration a.c. withstand voltage test). For three-phase reactors the test may be performed as a three-phase test or as three single-phase tests with an excitation circuit as given in Figure 5. If the power and voltage requirement for these tests exceeds those available at the test station, by agreement between manufacturer and purchaser, the short-time application of the test level U_1 may be reduced or omitted and the test duration extended.

If the power and voltage requirement for these tests exceeds those available at the test station, for reactors with a magnetic shield for zero-sequence flux, the single-phase test application as given in Figure 6 may be agreed between purchaser and manufacturer.

NOTE 2 The circuit shown in Figure 6 is not in accordance with IEC 60076-3:2000, 12.4, Figure 3. In the circuit shown in Figure 6, the voltage induced along the windings is equal to the voltage induced during the test according 12.4 but the voltage between windings of different phases is only 2/3 of the voltage induced during the test according 12.4 and is slightly less than U_m .

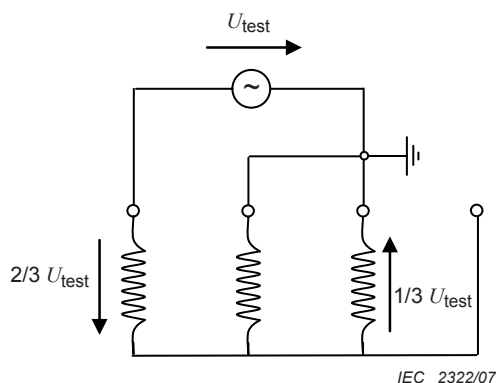


Figure 4 – Phase-to-earth test circuit for single-phase excitation

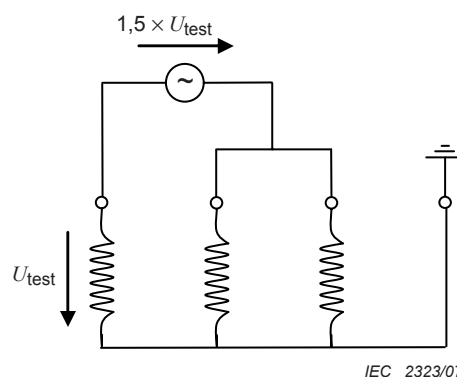


Figure 5 – Phase-to-phase test circuit for single-phase excitation

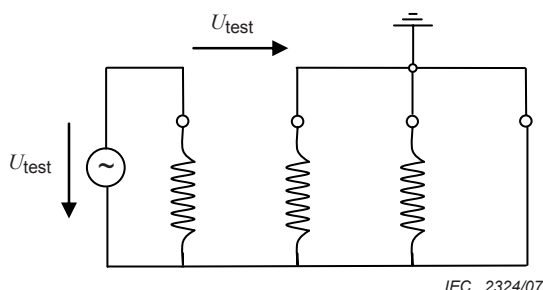


Figure 6 – Single-phase excitation circuit for reactors with magnetic shield for zero-sequence flux

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

7.8.10.4 Lightning impulse test (routine test)

A lightning impulse test including chopped waves shall be a routine test for liquid-immersed reactors, see Clauses 13 and 14 of IEC 60076-3:2000 and Clause 7 of IEC 60076-4:2002.

For dry-type reactors, a lightning impulse test according to Clause 13 of IEC 60076-3:2000 and Clause 7 of IEC 60076-4:2002 shall be applied. Alternatively, the turn-to-turn overvoltage test as described in Annex E may be used for reactors with $U_m \leq 36$ kV as a replacement test, unless otherwise specified.

7.8.10.5 Wet lightning impulse test applicable for dry-type reactors (special test)

When specified, the wet lightning impulse test shall be performed as described in 7.8.10.4 and with application of water spray as described in Clause 9 of IEC 60060-1:1989.

7.8.10.6 Switching impulse test (type test, routine test)

See Clause 15 of IEC 60076-3:2000 and 8.3 of IEC 60076-4:2002.

NOTE Usually, it is difficult to achieve the required waveshape during the test. When the manufacturer anticipates a difficulty in achieving the required waveshape, this should be discussed between manufacturer and purchaser at the earliest possible stage.

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

7.8.11 Measurement of magnetic characteristic (special test)

Measurement of the magnetic characteristic may be specified when the magnetic characteristic of the reactor is non-linear (Figure 1b) or saturated (Figure 1c).

The linked flux of the reactor windings cannot be measured directly. Therefore, an indirect method shall be used to establish the magnetic characteristic. The methods of measurement include instantaneous measurements of voltage and current at rated frequency, lower frequency measurements or the d.c. discharge test method, see Annex B. Alternative methods of measurement with an equivalent accuracy may also be used.

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

7.8.12 Measurement of acoustic sound level (type test, special test)

This measurement shall be made at rated voltage and frequency.

The test shall be made generally in accordance with IEC 60076-10. In some cases, the reactor noise may be disturbed by the noise of the test step-up transformer if it is placed near the reactor. Sound intensity measurements may be used to exclude any disturbing noise.

The test may be performed at any oil, winding and core temperature, but shall be carried out at an ambient temperature not lower than 10 °C. If the test is carried out as a special test, it shall be done at oil, winding and core temperatures as near as possible to service conditions, preferably in conjunction with the heat run test.

NOTE 1 The noise level of the reactor may be temperature dependent. Where a wide range of operating temperature is anticipated, noise measurements at two or more temperatures may be specified.

During measurements on dry-type reactors, sufficient safety clearances to the winding under test shall be ensured. The contour defined in Clause 7 of IEC 60076-10:2005 shall be located

2 m from the winding surface. The prescribed contour shall be located on a horizontal plane at half the winding height.

NOTE 2 For reactors with a high power rating, the test may be carried out on site subject to agreement between purchaser and manufacturer at the time of order, if the test cannot be carried out in the factory.

7.8.13 Measurement of vibration (type test)

7.8.13.1 General

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

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

7.8.13.2 Test conditions

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

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

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

The reactor shall be energized at maximum operating voltage and the rated frequency. Three-phase excitation is required for three-phase units. When the available test power is insufficient for testing at maximum operating voltage and/or three-phase excitation, the manufacturer shall demonstrate to the purchaser that reduced-voltage testing will produce sufficiently accurate results at the specified conditions. The test should preferably be performed at operating temperature, but may be done at ambient temperature.

7.8.13.3 Method of measurement

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

Measurements shall be taken on all four sides of the tank wall at a sufficient number of points to ensure that the maximum value of vibration has been measured.

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

7.8.13.4 Maximum vibration level

The maximum amplitude of tank wall displacement shall not exceed 200 μm peak-to-peak.

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

7.8.14 Temperature rise test (type test)

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

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

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

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

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 winding temperature rise above the oil temperature shall be multiplied by $\left(\frac{U_{\max}}{U_{\text{test}}}\right)^y$ with x and y according to the following:

- | | | |
|--------------------------------|-----------|-----------|
| • for reactors with ON cooling | $x = 0,8$ | $y = 1,3$ |
| • for reactors with OF cooling | $x = 1,0$ | $y = 1,3$ |
| • for reactors with OD cooling | $x = 1,0$ | $y = 2,0$ |

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

NOTE 2 For three-phase reactors with magnetic shield for zero-sequence flux, by agreement between manufacturer and purchaser, a temperature rise test may be made with d.c. current application to the windings. The oil temperature rises are measured at the d.c. current supplying the total corrected losses as determined according to 7.8.6.1. AC excitation of a single-phase at maximum voltage $U_{\max}$ is then used to measure the winding temperature rise above the oil temperature.

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

- | | |
|--------------------------------|-----------|
| • for reactors with AN cooling | $y = 1,6$ |
| • for reactors with AF cooling | $y = 1,8$ |

In most cases the total reactor loss at the steady-state condition is somewhat smaller than at reference temperature because the ambient temperature is normally lower than the design value during the test. This effect shall be neglected.

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

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

7.9 Tolerances

7.9.1 General

Unless otherwise specified, for shunt reactors with tapplings, the tolerances apply to the principal tapping.

7.9.2 Tolerances on reactance at rated voltage and rated frequency

The tolerance shall be within ± 5 % of rated reactance.

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

7.9.3 Tolerances on the linearity of reactance

For a linear reactor, the measurements of reactance made according to 7.8.5.3 shall be within ± 5 % of the reactance value measured at rated voltage.

7.9.4 Tolerance on loss

The total loss measured and corrected according to 7.8.6 shall not exceed the guaranteed loss by more than 10 %.

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 part of IEC 60076, 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.
- Converter or 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.

Depending on the specific application of such reactors, the requirements and tests as per Clause 8 of this part of IEC 60076 may not fully apply. Any deviation shall be agreed upon 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.

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 rated reactance at short-circuit current is therefore smaller than the reactance at rated continuous 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 Terms and definitions

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

8.3.1

rated continuous current

I_r

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

8.3.2

rated thermal short-circuit current

I_{scr}

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}

specified duration of the rated thermal short-circuit current

8.3.4

rated mechanical short-circuit current

I_{MSCr}

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

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}

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

8.3.8

rated reactance

X_{SCR}

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

8.3.9

mutual reactance X_m of a three-phase reactor

ratio between induced voltage in an open phase and the current in an excited phase in Ohms per phase at rated continuous current I_r and rated frequency (see also Figure 7)

8.3.10

coupling factor

k

mutual reactance expressed in per unit or percent of rated reactance

8.3.11

rated short-circuit impedance

Z_{SCR}

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

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

8.3.11.1

rated three-phase short-circuit impedance

Z_{SCR3}

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