

Reactors

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Committees responsible for this British Standard

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- Electricity Association
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Contents

	Page
Cooperating organizations	Inside front cover
National foreword	ii
Foreword	2
Text of EN 60289	5
National annex NA (informative) Original IEC text amended by CENELEC	49
National annex NB (informative) Cross-references	52

National foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It implements Harmonization document HD 539 S2, incorporating the corrigendum of January 1993, which was published by the European Committee for Electrotechnical Standardization (CENELEC). It is derived from IEC 60289:1988 *Reactors*, published by the International Electrotechnical Commission (IEC). This British Standard supersedes BS 4944:1973, which is withdrawn.

In 1994 the European Committee for Electrotechnical Standardization (CENELEC) accepted IEC 60289:1988 together with the common modifications for HD 539 S2 and some editorial modifications as European Standard EN 60289:1994. As a consequence of implementing the European Standard this British Standard is renumbered as BS EN 60289 and any reference to BS 4944 should be read as a reference to BS EN 60289.

The CENELEC common modifications have been implemented at the appropriate places in the text and are indicated by a sideline in the margin. Parts of the original IEC text that have been modified by CENELEC have been quoted in the National annex NA.

IEC 60070:1967, which is referred to in this standard, has been superseded by the following standards: IEC 60831-1:1988, IEC 60832-2:1992, IEC 60871-1:1987, IEC 60871-2:1987, IEC 60931-1:1989 and IEC 60931-2:1992. The following are corresponding British Standards.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled "International Standards Correspondence Index", or by using the "Search" facility of the *BSI Electronic Catalogue* or of British Standards Online.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 52, an inside back cover and a back cover.

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English version

Reactors

(includes amendment A11:2002)
(IEC 60289:1988, modified)

Bobines d'inductance
(inclut l'amendement A11:2002)
(CEI 60289:1988, modifiée)

Drosselspulen
(enthält Änderung A11:2002)
(IEC 60289:1988, modifiziert)

This European Standard was approved by CENELEC on 1993-09-22. Amendment A11 was approved by CENELEC on 2002-02-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Foreword

The text of the International Standard IEC 60289:1988, prepared by IEC TC 14, Power transformers, together with common modifications prepared by the Technical Committee CENELEC TC 14, Power transformers, was approved by CENELEC as HD 539 S2 on 1992-03-24.

At the request of TC 14 this Harmonization Document was submitted to the formal vote for conversion into a European Standard.

The text of IEC 60289:1988 with the common modifications accepted for HD 539 S2 and some editorial modifications was approved by CENELEC as EN 60289 on 1993-09-22.

The following dates were fixed:

- latest date of publication
of an identical national
standard (dop) 1994-07-01

Annexes designated “normative” are part of the body of the standard. In this standard, Annex ZA is normative.

Foreword to amendment A11

This amendment to the European Standard EN 60289:1994 was prepared by the Technical Committee CENELEC TC 14, Power transformers.

The text of the draft was submitted to the formal vote and was approved by CENELEC as amendment A11 to EN 60289:1994 on 2002-02-01.

The following dates were fixed:

- latest date by which the
amendment has to be
implemented at national
level by publication of an
identical national standard
or by endorsement (dop) 2003-02-01
- latest date by which the
national standards
conflicting with the
amendment have to be
withdrawn (dow) 2005-02-01

The reference of Clauses, Subclauses, Notes, Figures and Annexes which are in addition to those in IEC 60289 is prefixed with the letter Z.

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Annex ZB is informative.

Annex ZB has been added by CENELEC.

Contents

	Page	Page
Foreword	2	36 Rating 32
Section 1. General	5	37 Ability to withstand the rated neutral current 32
1 Scope	5	38 Temperature rise 32
2 Definitions	5	39 Insulation level 32
Section 2. Shunt reactors	7	40 Rating plates 32
3 General	7	41 Tests 33
4 Definitions	7	42 Tolerances 34
5 Rating	8	Section 7. Arc suppression reactors 35
6 Insulation level	8	43 General 35
7 Rating plates	8	44 Definitions 35
8 Tests	9	45 Rating 35
9 Tolerances	13	46 Adjustment range 36
Section 3. Current-limiting reactors and neutral-earthing reactors	15	47 Winding temperature rise 36
10 General	15	48 Insulation level 36
11 Definitions	15	49 Rating plates 36
12 Rating	16	50 Tests 37
13 Insulation level	17	51 Tolerances 38
14 Ability to withstand short-time current	17	Section 8. Smoothing reactors 39
15 Temperature rise	17	52 General 39
16 Rating plates	17	53 Definitions 39
17 Tests	18	54 Rating 39
18 Tolerances	21	55 Insulation level 39
Section 4. Damping reactors	23	56 Temperature rise 40
19 General	23	57 Rating plates 40
20 Definitions	23	58 Tests 40
21 Rating	23	59 Tolerances 43
22 Insulation level	23	Annex ZA (normative) Other international publications quoted in this standard with the references of the relevant European publications 48
23 Temperature rise	24	Annex ZB (informative) Installation and safety of a reactor 49
24 Rating plates	24	Figure 1 — Types of magnetic characteristic for shunt reactors (examples) 44
25 Tests	25	Figure 2 — Parameters for non-linear magnetic characteristic (example) 44
26 Tolerances	27	Figure 3 — Measurement of mutual reactance for three-phase reactors or banks of three single-phase reactors 45
Section 5. Tuning (filter) reactors	27	Figure 4 — Measuring circuit for determining inductance and loss at harmonic frequency for smoothing reactors having iron cores or shields 46
27 General	27	Figure 5 — Measuring circuit for determining incremental inductance of two identical large smoothing reactors 47
28 Definitions	28	Table I — Tolerances 38
29 Rating	28	
30 Rating plates	29	
31 Tests	30	
32 Tolerances	31	
Section 6. Earthing transformers (neutral couplers)	31	
33 Introduction	31	
34 General	31	
35 Definitions	31	

Section 1. General

1 Scope

This standard applies to the following types of reactors:

- shunt reactors;
 - reactors having windings with rated voltage U_n lower than, or equal to 1 000 V;
 - current-limiting reactors including neutral-earthing reactors;
 - damping reactors;
 - tuning (filter) reactors;
 - earthing transformers (neutral couplers);
 - arc suppression reactors;
 - smoothing reactors;
- with the exception of the following reactors:
- small reactors with a rating generally less than 2 kvar single-phase and 10 kvar three-phase;
 - reactors for special purposes such as high-frequency line traps or reactors mounted on rolling stock.

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

Where reference is made to specific Clauses and Subclauses of the various parts of IEC Publication 60076, Power Transformers, it is to be understood that the editions are to be as the CENELEC HD 398 in force.

2 Definitions

The definitions given in this Clause concern the categories of reactors which form the subject of Section 2 to Section 8 of this standard.

Additional definitions are given in those sections of terms which are specific to the particular category or which are given a particular meaning when related to that category.

Unless such definitions are given in this standard, the terms used have the meaning given in IEC Publication 60076.

Additional terms of more general nature are defined in the International Electrotechnical Vocabulary (IEV).

There are also frequent references to technical Clauses in IEC Publication 60076 and other related publications concerning transformers and transformer testing. The terminology of those publications has been maintained although it may not be strictly relevant in the context of reactors.

Test clauses should be followed as applicable concerning amplitudes, durations, test sequences, measurements and evaluation, even though specified test connections may not be applicable. For example “induced overvoltage 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 always applied directly from the test source.

2.1 Types of reactor

2.1.1

shunt reactor

reactor intended for parallel connection in a system to compensate for capacitive current

2.1.2

current-limiting reactor

reactor intended for series connection in a system for limiting the current under system fault conditions

2.1.3

neutral-earthing current-limiting reactor

single-phase reactor intended for connection between the neutral of a system and earth for limiting the line-to-earth current under system earth fault conditions to a moderate value

2.1.4

damping reactor

reactor intended for series connection with capacitors for limiting the inrush current during switching

2.1.5

tuning (filter) reactor

reactor intended for series or parallel connection with capacitors for reducing, blocking or filtering harmonics or communication frequencies

2.1.6

earthing transformer (neutral coupler)

three-phase transformer or reactor intended for parallel connection in a system to provide a neutral

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

2.1.7

arc suppression reactor

single-phase reactor intended for connection between the neutral of a system and earth for essentially compensating the capacitive line-to-earth current due to a single-phase earth-fault (resonant-earthed system)

2.1.8

smoothing reactor

reactor intended to reduce the flow of harmonic currents and transient overcurrents in d.c. systems

2.2.1

non-linearity

non-linearity of a reactor, at a specific applied voltage, is conventionally defined as the relative difference between the actual peak value of current and a value linearly proportioned, by the voltage, from the crest value of current at rated voltage. Measurement of voltage is, for this purpose, made with a measuring system responsive to mean value of voltage but scaled to read the r.m.s. value of a sinusoidal wave having the same mean value

NOTE The deviation is usually expressed in percent of the linearly proportioned current value.

2.3

service conditions

normal service conditions for reactors and the requirements for unusual service conditions are the same as specified for power transformers (IEC Publication 60076-1, Clause 2), as applicable. In certain countries the ambient temperature may temporarily be -30°C and even lower limits may be agreed upon

Z.1

Electromagnetic compatibility (EMC)

Reactors under the limits of Clause 1 shall be considered as a part of an installation. The EMC requirements are therefore those applicable to the whole installation

Section 2. Shunt reactors

3 General

3.1 Scope

Reactors intended for parallel connection in a system to compensate for capacitive current.

NOTE The absorbed reactive power at rated voltage can be firm or may be varied by use of additional devices:

- a) variation can be achieved, for example, by phase-controlled thyristors (static var source) or by d.c. magnetization of the iron core,
- b) variation can be achieved by winding tapplings, by means of an off-load or on-load tap-changer.

3.2 Design

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

- single-phase or three-phase;
- dry-type or oil-immersed;
- with air core or with gapped iron core;
- with or without magnetic shield;
- for indoor or outdoor installation;
- for fixed or variable reactance;
- having additional loading winding.

3.3 Magnetic characteristic

Knowledge of the entire magnetic characteristic as shown in Figure 1b) and Figure 1c) may be necessary:

- to set a normal operation range;
- for study of overvoltage conditions;
- for simulation in system studies.

Information on the magnetic characteristic should be supplied on request.

With regard to its entire magnetic characteristic the reactor is identified as:

- linear [Figure 1a)];
- non-linear [Figure 1b)];
- saturated [Figure 1c)].

The reactors with non-linear magnetic characteristic have their normal operation range in the linear part of the magnetic characteristic shown in Figure 2. The knee point and the slope in the saturated part may be subject to agreement between purchaser and manufacturer. They may be determined by measurement or by calculation.

4 Definitions

4.1

rated voltage U_N

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

the rated voltage U_N provides a basis for the design, the manufacturer's guarantees and the tests

NOTE For single-phase reactors intended to be associated in a three-phase bank, the rated voltage of a single 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:

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

4.2

maximum operating voltage $U_{\max}$

the highest voltage at rated frequency at which the reactor shall be capable of operating continuously without exceeding the specified temperature rises

NOTE 1 The rated voltage may be specified equal to the maximum operating voltage.

NOTE 2 Maximum operating voltage and rated voltage have to be specified by the purchaser.

4.3**rated power Q_N**

the reactive power specified for operation at rated voltage and frequency

4.4**rated current I_N**

the line current of the reactor 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 a single 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:

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

4.5**rated reactance X_N**

the reactance (in ohms per phase at rated frequency) specified at rated voltage

4.6**zero-sequence reactance X_0 (of a three-phase reactor)**

the reactance per phase at rated frequency, equal to three times the value measured between the line terminals of a three-phase star winding, connected together, and its neutral terminal

4.7**mutual reactance X_M (of a three-phase reactor)**

the ratio between induced voltage in an open phase and the current in an excited phase (in ohms per phase at rated frequency) (see Figure 3)

mutual reactance is suitably expressed per unit of the rated reactance

NOTE 1 The mutual reactance is also expressed by the “coupling factor” being equal to:

$$k = 100 X_M/X_N.$$

NOTE 2 For network considerations it should be noted, that the mutual reactance will generally be negligible for:

- a) a bank of three separate single-phase oil-immersed reactors;
- b) a bank of three single-phase air-core (dry-type) reactors in side-by-side arrangement;
- c) a three-phase reactor having continuous magnetic iron-path for zero-sequence flux.

5 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 the full load current with sinusoidal waveform unless otherwise specified.

6 Insulation level

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

7 Rating plates

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

7.1 Information to be given in all cases

Type of reactor.
Outdoor/indoor application.
Number of this standard.
Manufacturer's name.
Manufacturer's serial number.
Year of manufacture.
Number of phases.
Rated power.
Rated frequency.
Rated voltage.
Rated current.
Maximum operating voltage.
Insulation level(s).
Winding connection.
Reactance at rated voltage (measured value).
Type of cooling.
Total mass.
Mass of insulating oil.

7.2 Additional information to be given in certain cases

Thermal class of insulation (for dry-type reactors only).
Temperature rise (if not a normal value).
Transportation mass (for reactors exceeding 5 t total mass).
Untanking mass (for reactors exceeding 5 t total mass).
Type of insulating liquid, if not mineral oil.
Details regarding tapplings, if any.
Zero-sequence reactance.
Mutual reactance.

8 Tests

8.1 General requirements for routine, type and special tests

See Subclause 8.1 of IEC Publication 60076-1. The tests shall be carried out with the reactor erected substantially as in service, as far as features affecting the test results are concerned.

8.2 Routine tests

- a) Measurement of winding resistance (Subclause 8.3).
- b) Measurement of reactance (Subclause 8.6).
- c) Measurement of loss (Subclause 8.7).
- d) Dielectric tests (Subclause 8.11).
- e) Measurements of voltage ratio and short-circuit impedance on shunt reactors with additional loading winding.

8.3 Type tests

- a) Temperature-rise test (Subclause 8.15).
- b) Dielectric tests (Subclause 8.11).

8.4 Special tests

- a) Measurement of zero-sequence reactance on three-phase linear and non-linear reactors (Subclause 8.9).
- b) Measurement of mutual reactance on three-phase reactors (Subclause 8.10).
- c) Measurement of acoustic sound level (Subclause 8.13).
- d) Measurement of vibration (Subclause 8.14).
- e) Measurement of harmonics of the current (Subclause 8.8).
- f) Measurement of power taken by fans and oil pumps, if any.
- g) Measurement of magnetic characteristic (Subclause 8.12).

8.5 Measurement of winding resistance

See Subclause 8.2 of IEC Publication 60076-1.

8.6 Determination of reactance

- a) The reactance of single phase reactors is determined as the ratio of the rated voltage to the measured current (r.m.s. value) at rated voltage assuming that the resistive component of impedance is negligible.
- b) The reactance shall be determined at rated frequency by applying an approximately sinusoidal supply (see IEC 60060-1:1989, Subclause 16.1).
- c) For reactors which have neither gapped iron core nor magnetic shield, the measurements may be made at any voltage between 10 % and 100 % of rated voltage.
- d) For reactors having gapped iron core or magnetic shield, the measurements shall be made at rated voltage. In exceptional cases, e.g. extremely large rated power and high system voltage, it may be difficult to maintain these test conditions. For linear and non-linear reactors, extrapolation of approximately 10 % is allowed, i.e. the test voltage shall in all cases exceed $0.9 U_N$.
- e) 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:

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

For three-phase reactors with magnetic iron-path for zero-sequence flux, the reactance measurement may also be performed with single-phase excitation.

NOTE When the testing installation does not allow a satisfactory test, it may be made on site, subject to agreement between purchaser and manufacturer.

8.7 Measurement of loss

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.

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 voltage 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 method for determination of loss is subject to agreement between purchaser and manufacturer; satisfactory documentation regarding accuracy and reliability of the proposed method shall be provided.

As the power factor of a shunt reactor is normally very low, loss measurement using conventional wattmeter methods may be subject to considerable errors.

A bridge method may be used to advantage. A calorimetric method can be used in special cases.

The loss in the various parts of the reactor (I^2R loss, iron loss and additional loss) cannot be separated by measurement; it is thus preferable, in order to avoid corrections to reference temperature, to perform the measurement when the average temperature of the windings is practically equal to the reference temperature.

If this is impracticable, the additional loss as well as the iron loss shall be deemed independent of temperature.

If several units are to be tested, it is recommended that the unit on which loss measurement is carried out as a type test at approximately reference temperature, shall be measured at ambient temperature also, thus establishing a temperature coefficient for total loss (assuming linear variation). Remaining units will then be measured at ambient temperature only, and their loss Figure shall be corrected to reference temperature using the temperature coefficient established on the type tested unit.

If, at rated voltage, the current measured is different from the rated current, the measured loss shall be multiplied by the square of the ratio of rated current to measured current.

NOTE See note to Subclause 8.6.

8.8 Measurement of harmonics of the current

This measurement applies to reactors with saturated magnetic characteristic [see Figure 1c)]. The harmonics of the current in all three phases are measured at rated voltage by means of a harmonic analyser and the magnitude of the relevant harmonics is expressed as a percentage of the fundamental component. The harmonics of the applied voltage shall be adequately measured at the same time.

NOTE This test is practicable only if the distortion factor of the applied voltage is less than 2 % (see Subclause 16.1 of IEC 60060-1:1989).

8.9 Measurement of zero-sequence reactance on three-phase linear and non-linear reactors

See Subclause 8.7 of IEC Publication 60076-1.

This measurement has to be carried out at a voltage corresponding to a neutral current not exceeding the rated phase current.

8.10 Measurement of mutual reactance on three-phase reactors

The measurement shall be made preferably at rated voltage according to Figure 3.

NOTE Care should be taken to prevent voltages induced by currents flowing in connecting leads. Details given in Subclause 17.5, about this subject, for series reactors, are also applicable.

8.11 Dielectric tests

The application of different dielectric tests to shunt reactors in general follows the corresponding rules for transformers in IEC Publications 60076-3, 60722 and 60726.

8.11.1 *Separate-source voltage withstand test (routine test)*

See Clause 10 of IEC Publication 60076-3.

8.11.2 *Induced overvoltage withstand test (routine test)*

The induced overvoltage withstand test is carried out in general accordance with Clause 11 of IEC Publication 60076-3, except as otherwise described below.

If the reactor is uniformly insulated Subclause 11.2 applies.

If the reactor is non-uniformly insulated either Subclause 11.3 or Subclause 11.4 applies, depending upon test voltage and test facilities available.

The test according to Subclause 11.4 is the only alternative at $U_m \geq 245$ kV but may be used by agreement between purchaser and manufacturer at lower voltages as well. When the test according to Subclause 11.4 is applied, it is modified as follows:

The partial discharge measurement shall be performed with test voltage $U_2 = 1.5 U_m / \sqrt{3}$, the short-time application of the enhanced level U_1 being omitted.

If the power and voltage requirements for these tests exceed those available at the test station, the test shall be replaced by agreement between purchaser and manufacturer by a lightning impulse test.

Test voltages and test methods have to be agreed upon at the time of the order.

NOTE For dry-type reactors, also see Clause 20 of IEC Publication 60726.

8.11.3 *Lightning impulse test (type and routine test)*

See Clauses 12 and 13 of IEC Publication 60076-3, or Clause 19 of IEC Publication 60726 and IEC Publication 60722.

8.11.4 *Switching impulse test (type and routine test)*

See Clause 14 of IEC Publication 60076-3 and Subclause 7.3 of IEC Publication 60722.

8.12 Measurement of magnetic characteristic

A measurement of the magnetic characteristic may be specified when the reactor is non-linear [Figure 1b)] or saturated [Figure 1c)]. The measurement may be conducted with power frequency voltage and current up to maximum operating voltage or, by agreement between purchaser and manufacturer, slightly above this value.

NOTE The magnetic characteristic may also be obtained by processing records from charging or discharging the reactor with d.c. current.

8.13 Measurement of acoustic sound level

This test should be made in general accordance with IEC Publication 60551.

During measurements on dry-type reactors, sufficient safety clearances to the winding under test have to be ensured.

The contour defined in Subclause 2.5 of IEC Publication 60551 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 For large power rating reactors, if not possible in the factory, the test may be carried out on site subject to agreement between purchaser and manufacturer.

8.14 Measurement of vibration

If measurement of vibration is specified, the following items shall be agreed upon before the test is carried out:

- whether the test shall be made as a type test on one unit or as a routine test on all units;
- whether the test shall be run at rated voltage or maximum operating voltage, if different;
- where and how the measurements shall be taken (normally on all four sides of the tank wall and at a sufficient number of points to permit an averaging procedure and on the extremities of any equipment mounted on the tank).

The measurements shall be expressed in terms of peak-to-peak amplitude of vibration.

A recommended maximum value is 200 μm for the tank wall.

For the equipment mounted on the tank it has to be shown by the manufacturer that the amplitudes have no long-term effect on their stability and performance.

8.15 Temperature rise test

See IEC Publication 60076-2.

This test is performed preferably at maximum operating voltage and rated frequency.

If the maximum operating voltage cannot be maintained during the test, it may be performed at reduced voltage but not less than 90 % of maximum operating voltage. The temperature rises shall be corrected to the maximum operating voltage according to IEC Publications 60076-2 or 60726, for oil-immersed and dry-type reactors respectively.

9 Tolerances

In the case of shunt reactors with tapplings, the tolerances apply to the principal tapping unless otherwise specified.

9.1 Tolerances on reactance at rated voltage and rated frequency

± 5 % of rated reactance.

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

If a reactor is specified with a characteristic according to Figure 1b), a tolerance on variation of reactance of ± 5 % of the reactance value measured at rated voltage shall apply up to a limit of voltage specified by the purchaser.

9.2 Tolerance on loss

The total loss measured and corrected according to Subclause 8.7 shall not exceed the guaranteed loss by more than 15 %.

9.3 Tolerance on secondary voltage

If a shunt reactor is specified with a secondary winding (see 3.2 “Design”) having a continuous rated power, e.g. for station auxiliary supply, the tolerance on its no-load voltage at rated voltage across the main winding is +10 % of the specified value.

