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FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This publication has been prepared by IEC Technical Committee No. 14, Power Transformers.

It is the fifth of a series of five parts which, when completed, will supersede the second edition of Publication 76 (1967).

A first draft was discussed at the meeting held in Brussels in 1971, as a result of which a draft, Document 14(Central Office)22, was submitted to the National Committees for approval under the Six Months' Rule in September 1972.

The following countries voted explicitly in favour of publication:

Argentina
Australia
Austria
Belgium
Canada
Denmark
Finland
France
Germany
Hungary
Israel
Italy
Japan
Netherlands
Norway
Portugal
Romania
South Africa (Republic of)
Spain
Sweden
Turkey
Union of Soviet Socialist Republics
United Kingdom
United States of America
Yugoslavia

Publication 76 has been divided into the following five parts, which are published as separate booklets:

Publication 76-1: Part 1: General.
Publication 76-2: Part 2: Temperature Rise.
Publication 76-3: Part 3: Insulation Levels and Dielectric Tests.
Publication 76-4: Part 4: Tappings and Connections.
Publication 76-5: Part 5: Ability to Withstand Short Circuit.

Pending publication of Part 3, which will be issued at a later date, the insulation levels and dielectric test requirements of Publication 76 (1967) continue to apply.

POWER TRANSFORMERS

Part 5: Ability to withstand short circuit

1. Requirements with regard to ability to withstand short circuit

1.1 *General*

Transformers shall be designed and constructed to withstand without damage the thermal and dynamic effects of external short circuits under the conditions specified in Sub-clause 1.2.

External short circuits are not restricted to three-phase short circuits: they include line-to-line, double-earth and line-to-earth faults. The currents resulting from these conditions in the windings are designated as "*overcurrents*" in this part of Publication 76.

1.2 *Overcurrent conditions*

1.2.1 *Transformers with two separate windings*

1.2.1.1 Three categories for the rated power of three-phase transformers or three-phase banks are recognized:

category I, up to 3 150 kVA;

category II, 3 151 kVA to 40 000 kVA;

category III, above 40 000 kVA.

1.2.1.2 The symmetrical short-circuit current (r.m.s. value, see also Sub-clause 2.1.2) shall be calculated using the short-circuit impedance of the transformer plus the system impedance for transformers of categories II and III and also for transformers of category I if the system impedance is greater than 5% of the short-circuit impedance of the transformer.

TABLE I

Typical values of impedance voltage for transformers with two separate windings

Impedance voltage at rated current, given as a percentage of the rated voltage of the winding to which the voltage is applied	
Rated power kVA	Impedance voltage %
Up to 630	4.0
631 to 1 250	5.0
1 251 to 3 150	6.25
3 151 to 6 300	7.15
6 301 to 12 500	8.35
12 501 to 25 000	10.0
25 001 to 200 000	12.5

Notes 1. — Values for rated powers greater than 200 000 kVA are subject to agreement between the manufacturer and the purchaser.

2. — In the case of single-phase units connected to form a three-phase bank, the value of rated power applies to the three-phase bank.

For transformers of category I, the system impedance shall be neglected in the calculation if this impedance is equal to or less than 5% of the short-circuit impedance of the transformer.

The peak value of the short-circuit current shall be calculated in accordance with Sub-clause 2.2.3.

1.2.1.3 Typical values for the short-circuit impedance of transformers expressed as the impedance voltage at rated current (principal tapping) are given in Table I. If lower values are required, the ability of the transformer to withstand a short circuit shall be subject to agreement between the manufacturer and the purchaser.

1.2.1.4 The short-circuit apparent power of the system at the transformer location should be specified by the purchaser in his enquiry in order to obtain the value for the symmetrical short-circuit current to be used for the design and the tests.

If the short-circuit level is not specified, the values given in Table II may be used.

TABLE II

Short-circuit apparent power of the system which may be used in the absence of other specifications

Highest system voltage kV	Short-circuit apparent power MVA
7.2, 12, 17.5 and 24	500
36	1 000
52 and 72.5	3 000
100 and 123	6 000
145 and 170	10 000
245	20 000
300	30 000
420	40 000

1.2.2 *Transformers with more than two windings and auto-transformers*

The overcurrents in the windings, including stabilizing windings and auxiliary windings, shall be determined from the impedances of the transformer and the system(s). Account shall be taken of the effect of possible feedback from rotating machinery or from other transformers as well as of the different forms of system faults that can arise in service, e.g. line-to-earth faults and line-to-line faults associated with the relevant system and transformer earthing conditions. The characteristics of each system (at least the short-circuit level and the range of the ratio between the zero-sequence impedance and the positive-sequence impedance) shall be specified by the purchaser in his enquiry.

When the combined impedance of the transformer and the system(s) results in excessive overcurrent, the manufacturer shall advise the purchaser of the maximum overcurrent that the transformer can withstand. In this case, provision should be made by the purchaser to limit the short-circuit current to the overcurrent indicated by the manufacturer.

Stabilizing windings of three-phase transformers shall be capable of withstanding the overcurrents resulting from different forms of system faults that can arise in service associated with relevant system earthing conditions.

It may not be economical to design auxiliary windings to withstand short circuits on their terminals. In such a case, the effect of the overcurrents has to be limited by appropriate means, such as series reactors or, in some instances, fuses. Care has to be taken to guard against faults in the zone between the transformer and the protective apparatus.

In the case of single-phase transformers connected to form a three-phase bank, the stabilizing windings shall be capable of withstanding a short circuit on their terminals, unless the purchaser specifies that special precautions will be taken to avoid short circuits between phases.

1.2.3 *Booster transformers*

The impedances of booster transformers can be very low and, therefore, the overcurrents in the windings are determined mainly by the characteristics of the system at the location of the transformer. These characteristics shall be specified by the purchaser in his enquiry.

When the combined impedance of the transformer and the system results in excessive overcurrent, the manufacturer shall advise the purchaser of the maximum overcurrent that the transformer can withstand. In this case, provision should be made by the purchaser to limit the short-circuit current to the overcurrent indicated by the manufacturer.

1.2.4 *Transformers directly associated with other apparatus*

Where a transformer is directly associated with other apparatus, the impedance of which would limit the short-circuit current, the sum of the impedances of the transformer, the system and the directly-associated apparatus may, by agreement between the manufacturer and the purchaser, be taken into account.

This applies, for example, to generator transformers if the connection between generator and transformer is constructed in such a way that the possibility of line-to-line or double-earth faults in this region is negligible.

Note. — If the connection between generator and transformer is constructed in this way, the most severe short-circuit conditions may occur, in the case of a star-delta-connected generator transformer with earthed neutral, when a line-to-earth fault occurs on the system connected to the star-connected winding.

1.2.5 *Special transformers*

The ability of a transformer to withstand frequent overcurrents, arising from the method of operation or the particular application (e.g. furnace transformers and traction-feeding transformers) shall be subject to special agreement between the manufacturer and the purchaser.

1.2.6 *Tap-changing equipment*

Where fitted, tap-changing equipment shall be capable of carrying the same overcurrents due to short circuits as the windings.

1.2.7 *Neutral terminals*

The neutral terminal of windings with star or zigzag connection shall be designed for the highest overcurrent that can flow through this terminal.

2. Demonstration of ability to withstand short circuit

2.1 *Thermal ability to withstand short circuit*

2.1.1 *General*

According to this standard, the thermal ability to withstand short circuit is demonstrated by calculation.

2.1.2 *Value of the symmetrical short-circuit current I for transformers with two windings*

The r.m.s. value of the symmetrical short-circuit current I is calculated for three-phase transformers as follows:

$$I = \frac{U}{(Z_t + Z_s)\sqrt{3}}, \text{ in kiloamperes} \qquad (1)$$

where:

Z_s is the short-circuit impedance of the system

$$Z_s = \frac{U_s^2}{S}, \text{ in ohms per phase} \qquad (2)$$

U_s is the rated voltage of the system, in kilovolts, and S is the short-circuit apparent power of the system, in megavoltamperes.

U and Z_t are defined as follows:

a) for the principal tapping:

U is the rated voltage U_N of the winding under consideration, in kilovolts

Z_t is the short-circuit impedance of the transformer referred to the winding under consideration, and is calculated as follows:

$$Z_t = \frac{u_z \, U_N^2}{100 \; S_N} \text{, in ohms per phase} \qquad (3)$$

where u_z is the impedance voltage at rated current and at the reference temperature, as a percentage, and S_N is the rated power of the transformer, in megavoltamperes;

b) for tappings other than the principal tapping:

U is, unless otherwise specified, the tapping voltage * of the tapping and the winding under consideration, in kilovolts

Z_t is the short-circuit impedance of the transformer referred to the winding and the tapping under consideration, in ohms per phase.

For transformers of category I, the impedance of the system is neglected in the calculations if it is equal to or less than 5% of the short-circuit impedance of the transformer (see also Sub-clause 1.2.1.2).

If the short-circuit power of the system is not specified by the purchaser in the enquiry, its value can be taken from Table II.

Note. — For the purposes of this sub-clause, the designation Z_t has been used for short-circuit impedance of the transformer which is designated by Z_K in Sub-clause 3.7.4. of Part 1.

2.1.3 *Duration of the symmetrical short-circuit current I*

The duration of the current I to be used for the calculation of the thermal ability to withstand short circuit is 2 s, unless otherwise specified by the purchaser.

Note. — For auto-transformers and for transformers with a short-circuit current exceeding 25 times the rated current, a short-circuit current duration below 2 s may be adopted after agreement between the manufacturer and the purchaser.

2.1.4 *Maximum permissible value of the highest average temperature θ_1*

On the basis of an initial winding temperature θ_0, derived from the sum of the maximum permissible ambient temperature and the relevant temperature rise at rated conditions measured by resistance (or, if this temperature rise is not available, the temperature rise for the relevant temperature class of the insulation of the winding), the highest average temperature θ_1 of the winding, after loading with a symmetrical short-circuit current I of a value and duration as described in Sub-clauses 2.1.2 and 2.1.3, shall not exceed the value stated for θ_2 in Table III in any tapping position.

TABLE III

Maximum permissible values of average temperature of the winding after short circuit, θ_2

Transformer type	Temperature class of insulation	Value of θ_2	
		Copper	Aluminium
Oil-immersed	A	250 °C	200 °C
Dry	A E B F and H	180 °C 250 °C 350 °C 350 °C	180 °C 200 °C 200 °C —

* For a definition of "tapping voltage", see Sub-clause 3.5.3.3 of Publication 76-1, Part 1: General.