
Guide on power transformers

Part 1. Application of power transformers

[IEC title : Application guide for power transformers]

Guide pour les transformateurs de puissance
Partie 1. L'application des transformateurs de puissance

Anleitung zu Leistungstransformatoren
Teil 1. Anwendung von Leistungstransformatoren

National foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Committee. It is identical with IEC Publication 606 : 1978 'Application guide for power transformers' published by the International Electrotechnical Commission (IEC). It supersedes appendices C and E of BS 171 : 1970

Terminology and conventions. The text of the international standard has been approved as suitable for publication, without deviation, as a British Standard. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

The comma has been used in figures 5, 6 and 7 as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Where page numbers are quoted in the text, they refer to IEC page numbers.

Cross-references

International standard	Corresponding British Standard
IEC 76	BS 171 Power transformers
IEC 76-1 : 1976	BS 171 : Part 1 : 1978 General (Identical)
IEC 76-4 : 1976	BS 171 : Part 4 : 1978 Specification for tapplings and connections (Identical)

NOTE. *Textual error in 2.4.3e).* In line 2 of the note the penultimate word should read 'or'.

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British Standard

Guide on power transformers

Part 1. Application of power transformers

1. Scope and object

1.1 Scope

This application guide applies to power transformers complying with IEC Publication 76, Power Transformers (1976).

1.2 Object

This application guide is intended to assist in the determination and selection of transformer characteristics. The recommendations given herein are not mandatory, and are solely for the guidance of purchasers at the time of purchase and during subsequent usage.

2. Specification of tapping quantities

2.1 Introduction

2.1.1 Purpose of this clause

The main purpose of this clause is to help the purchaser to determine from the on-load operating conditions of the transformer the tapping quantities to be specified in accordance with Section One of Publication 76-4, Part 4: Tappings and Connections.

Since the tapping quantities are used as a basis for the manufacturer's guarantees and for tests, they should not be unduly complex, since that would make the assessment of guarantees too difficult.

A transformer complying with this specification should be capable of operating under the expected on-load conditions without being needlessly oversized (see note). Amongst all the solutions meeting this condition, the simplest ones should be sought, taking into account the information given in IEC Publication 76-4, in Clauses 3, 4 and 5 relating to "constant flux voltage variation", "variable flux voltage variation" and "combined voltage variation".

Note. — For the purposes of standardization and simplification, the theoretically calculated data (rated power, voltage data, etc.) resulting from assumed on-load operating conditions may be adjusted when deciding the final transformer data. Such considerations, which can result in an "oversized" transformer, are mostly disregarded in this guide.

2.1.2 Field of application

In this guide, as in IEC Publication 76-4, the only case considered is the most common, of a transformer having only one tapped winding.

Note. — To simplify demonstration, consideration is limited to two-winding transformers (to which can be added a stabilizing or auxiliary winding).

2.1.3 Abbreviations used in this clause

To shorten the text and the figures, the following abbreviations are used for certain quantities which often appear (sub-script A refers to the tapped winding and sub-script B to the untapped winding):

U_A = tapping voltage of the tapped winding

I_A = tapping current of the tapped winding

U_B = tapping voltage of the untapped winding

I_B = tapping current of the untapped winding

K_A = tapping factor (see definition in Sub-clause 3.5.1.2 of IEC Publication 76-1, Part 1: General)

n = voltage ratio

n_u = voltage ratio on the maximum voltage tapping

n_i = voltage ratio on the maximum current tapping

n_p = voltage ratio on the principal tapping (rated voltage ratio)

2.2 First stage of determination of tapping duties (converting from on-load voltages to "no-load" voltages). Calculation of voltage ratios

To determine from on-load quantities the tapping quantities to be specified and particularly the tapping voltages (see definition in Sub-clause 3.5.3.3 of IEC Publication 76-1) it will be necessary to replace the on-load voltages of the various windings by no-load voltages by making suitable voltage corrections.

First of all, voltage drop (or voltage rise) ΔU is calculated *, taking into account the following information:

- load in MVA, power factor $\cos \phi$ and $\sin \phi$;
- direction of the power flow;
- variation range of the high voltage (H.V.);
- variation range of the low voltage (L.V.).

Voltage corrections are then made by multiplying the on-load voltage by $\frac{100}{100 - \Delta U}$ where ΔU is expressed in percentage.

The voltage ratios and particularly their extreme values are then obtained from these calculated "no-load voltages".

Note. — The voltage drop or rise calculations can be based on approximate impedance values. More accurate calculations can be made when the final impedance values are known, but this is not often necessary.

2.3 Choice of the tapped winding

For technical reasons it is usually preferable for tapplings to be located:

- a) on the high-voltage winding rather than on the low-voltage winding, particularly if the voltage ratio is high;
- b) on a star-connected winding rather than on a delta-connected winding;
- c) on the winding of which the tapping voltage varies the most. This factor is less important than the factors mentioned in Items a) and b).

* For this calculation, see Clause 6.

2.4 Determination of the tapping quantities of a separate winding transformer—The six parameter method

In this sub-clause only separate winding transformers are considered, auto-transformers being considered in Sub-clause 2.5.

2.4.1 General

The result of the first stage of the calculation will generally lead to several tapping duties per tapping, but generally such a complication is not justified in practice and is therefore disregarded in this guide. The simplification of using only one tapping duty per tapping may result in a slight oversizing of the transformer compared with one which fulfils only and exactly the assumed loading conditions. As in practice these assumed loading conditions can be only approximations, only in exceptional cases should more than one tapping duty per tapping be used.

A further simplification is to use tapping currents and tapping voltages following the simple laws of variation, as a function of the tapping factor, which are considered in Clauses 3, 4 and 5 and illustrated in Figures 1 to 3 of IEC Publication 76-4.

These simplifications are used in the method described in Sub-clauses 2.4.2 to 2.4.4.

As a preliminary, some explanations follow relating to the “maximum voltage tapping” of the combined voltage variation and to the “maximum current tapping”;

a) “Maximum voltage tapping” in the case of “combined voltage variation”

In transformers employing “combined voltage variation” there is a maximum voltage tapping, above which the tapping voltages of the tapped winding remain constant. In the untapped winding, “tapping voltages” are constant up to this tapping and decrease for higher tappings.

The introduction of a “maximum voltage tapping” eliminates the specification of unrealistically high tapping voltages which may otherwise even considerably exceed the “highest voltage for equipment”.

This limitation of the tapping voltages of certain tappings also means, on these tappings, a limitation of the calculated maximum short-circuit current for which the mechanical withstand ability of the transformer has to be guaranteed.

b) “Maximum current tapping” and temperature rise

Sub-clauses 3.2b), 4.2b) and 5.2b) of Section One in IEC Publication 76-4 and particularly Figures 1b, 2b, 3b which illustrate them, present simple laws of the variation of tapping currents as a function of the tapping factor, based upon a “maximum current tapping”. For this tapping, the tapping currents of the two windings are simultaneously a maximum. On each side of this tapping one of the tapping currents remains constant and maximum while the other decreases so that, in practice, it follows that the total losses and the temperature rise of the windings decrease on either side of this tapping. Therefore, this maximum current tapping is also the maximum temperature-rise tapping.

2.4.2 The six parameters of a two-winding transformer

Only two-winding transformers are considered (see Sub-clause 2.1.2).

In the following method, the data used for the determination of the tapping quantities are limited to the following six parameters:

a) the extreme voltage ratios: $n_{\min}$ and $n_{\max}$;

- b) maximum voltage of each winding: $(U_{HV})_{\max}$ and $(U_{LV})_{\max}$;
 c) maximum current of each winding: $(I_{HV})_{\max}$ and $(I_{LV})_{\max}$.

The numerical values of these six parameters are known when the first stage of the calculation has been completed (see Sub-clause 2.2).

2.4.3 Calculation procedure for the tapping quantities, based on the six parameters

The numerical values of the six parameters are used for preparing a table of tapping quantities as a function of the voltage ratio n and of the tapping factor K_A such as in Table I. The calculation procedure is as follows:

- a) Give in the first column the four voltage ratios:

$$n_{\min}, n_i = (I_{LV})_{\max} / (I_{HV})_{\max}, n_u = (U_{HV})_{\max} / (U_{LV})_{\max} \text{ and } n_{\max}$$

Enter them in numerical order (Table I assumes increasing order from the top and n_u is supposed to be higher than n_i but in some cases n_i can be higher than or equal to n_u).

Prepare also a line for the principal tapping which, for the reasons reiterated in Sub-clause 2.4.3d), will be placed between the lines $n = n_i$ and $n = n_u$. Write 100 as the value of K_A , the value of n , namely n_p , being still undetermined.

- b) Enter in the table the maximum voltage and current values for each winding as shown in Table I.

— $(U_{LV})_{\max}$ from $n_{\min}$ to n_u and $(U_{HV})_{\max}$ from n_u to $n_{\max}$;

— $(I_{HV})_{\max}$ from $n_{\min}$ to n_i and $(I_{LV})_{\max}$ from n_i to $n_{\max}$.

- c) Complete the table with those missing values of voltage and current marked (2) in the table. The appropriate voltage or current value is deduced from the value of voltage or current of the other winding and of the value of voltage ratio n .

The tapping power (3) is then calculated.

- d) Choose the tapped winding and the principal tapping. From the definitions of the principal tapping and of the full-power tapplings, this is one of the full-power tapplings, i.e. one of the tapplings ranging from the “maximum voltage tapping” to the “maximum current tapping”.

The simplest solution is to take the mean tapping if it is a full-power tapping or, if not, the full-power tapping which is the closest to the mean tapping.

- e) The tapping factor K_A can then be calculated.

$K_A = n/n_p$ if the tapplings are on the H.V. winding;

$K_A = n_p/n$ if the tapplings are on the L.V. winding.

Furthermore, n_p being known, the line “principal tapping” can be completed. This line gives the rated values of voltages, currents and power.

The table is thus complete.

Note. — The preceding method generally leads to combined voltage variation. However, if n_u is equal to an extreme value of n , the category of voltage variation is “constant flux voltage variation” of “variable flux voltage variation”, according to whether the maximum voltage tapping is the extreme plus tapping or the extreme minus tapping. Furthermore, if the maximum voltage tapping, without being the extreme plus tapping, is close enough to it, the combined voltage variation can be changed into constant flux voltage variation in order to simplify still more the specification of the tapping quantities (see Sub-clause 2.7).

TABLE I

Table of tapping quantities

n (1)	K_A (%)	Voltages		Currents		Power	Tapping Designation
		H.V.	L.V.	H.V.	L.V.		
$n_{\min} = \dots$	(4)	(2)	$(U_{LV})_{\max}$	$(I_{HV})_{\max}$	(2)	(3)	Minimum voltage ratio tapping
$n_i = \dots$	(4)	(2)	$(U_{LV})_{\max}$	$(I_{HV})_{\max}$	$(I_{LV})_{\max}$	$S_{\max}$ (3)	Maximum current tapping
$n_p = \dots$ (5)	100	(5)	$(U_{LV})_{\max}$	(5)	$(I_{LV})_{\max}$	$S_{\max}$	Principal tapping
$n_u = \dots$	(4)	$(U_{HV})_{\max}$	$(U_{LV})_{\max}$	(2)	$(I_{LV})_{\max}$	$S_{\max}$ (3)	Maximum voltage tapping
$n_{\max} = \dots$	(4)	$(U_{HV})_{\max}$	(2)	(2)	$(I_{LV})_{\max}$	(3)	Maximum voltage ratio tapping
(1) The table assumes $n_u > n_i$. (2) To be completed with the appropriate values of voltage or current, deduced from the voltage or current of the other winding and of the voltage ratio n. (3) Power is calculated from voltage and current values. (4) After choosing the tapped winding and the principal tapping, tapping factors K_A are calculated. (5) To be filled in after choosing the principal tapping, i.e. n_p.							

- f) The various values can now be rounded off, particularly the rated power. This rounding off and the use of a suitable number of steps naturally affects somewhat the voltage and current values. Furthermore, the possibility of operation at voltages higher than the tapping voltage can be considered (see Sub-clause 2.6).

When the preceding calculations have led to the choice of an extreme tapping as the maximum current tapping, it may be advisable to re-examine this choice as indicated in Clause A4 of Appendix A.

- g) For specification purposes the table can be abbreviated, as the numerical data of the table can actually be obtained from the following more concentrated data, according to IEC Publication 76-4, (Sub-clause 5.2):

- rated power and rated voltages;
- which winding is the tapped winding, and its tapping range;
- the number of tapping positions or the value of the tapping step;
- which tapping is the “maximum voltage tapping” with the corresponding tapping voltages;
- which tapping is the “maximum current tapping”.

2.4.4 Examples of application of this method

Three examples are given in Appendix A.

2.5 *Tapping currents of auto-transformers*

For separate-winding transformers, Sub-clause 2.4.2c) considered two parameters corresponding to the maximum currents of the windings, namely $(I_{HV})_{\max}$ and $(I_{LV})_{\max}$.

For auto-transformers, the windings to be considered are the series winding and the common winding. The maximum current of the series winding is equal to $(I_{HV})_{\max}$, but the maximum current of the common winding is equal to the maximum value of the difference $(I_{LV} - I_{HV})$.

For this reason, the “maximum current tapping”, based on $(I_{HV})_{\max}$ and $(I_{LV})_{\max}$ does not have the physical meaning it has for separate winding transformers (see Sub-clause 2.4.1). As a consequence, it would in theory be inappropriate to base the current requirements on such a tapping, and a more elaborate specification of the tapping quantities would be needed.

However, in practice, auto-transformers can generally be treated in the same manner as separate winding transformers, provided it is verified that the common winding meets the standard temperature rise guarantees throughout the tapping range. This verification can normally be provided by calculation from one single temperature-rise test with the transformer connected on a suitable tapping.

An example is given in Clause A5 of Appendix A.

2.6 *Possibilities of operation at voltages higher than the tapping voltages*

The possibilities of continuous operation at increased voltage at full current or at reduced current are given in Sub-clause 4.4 of IEC Publication 76-1 for the principal tapping and in Sub-clause 2.7 of IEC Publication 76-4 for the other tappings.

2.6.1 *Possibilities during full-current operation*

As a general rule, the 5% overvoltage margin allowed in IEC Publication 76-1 is used to meet exceptional circumstances, for instance system outages.

2.6.2 *Possibilities during reduced current operation*

As provided in IEC Publication 76-1, the purchaser may specify that the transformer shall be capable of operation at voltages higher than the tapping voltage, for example, of operation at 110% of this voltage at no-load and at 108.75% at half-load.

2.7 *Conversion of “combined voltage variation” into “constant flux voltage variation”*

The principle of this conversion is that the tapping voltage U_B of the untapped winding, instead of reaching its maximum value for only some tappings, retains this value for all the tappings. The voltage U_A of the tapped winding is no longer “cut at the top”.

Resulting from this conversion, voltages U_B and U_A , and thereby the tapping power, are increased for the whole of the former “variable flux range” *.

The main advantage is simplification. Moreover, this conversion can also lead to a better indication of the overall voltage and power capability of the transformer when operated on those tappings of which the voltage and power have been increased.

* See also Figure 5, page 50, Appendix A, which shows a graphical illustration relating to example 1 of the Appendix.