

Electric cables — Calculation of the current rating —

**Part 1: Current rating equations
(100 % load factor) and calculation of
losses —**

**Section 1.2: Sheath eddy current loss
factors for two circuits in flat formation**

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Cables and Insulation Standards Policy Committee (CIL/-) to Technical Committee CIL/20, upon which the following bodies were represented:

- Association of Consulting Engineers
- Association of Manufacturers of Domestic Electrical Appliances
- BEAMA Electrical Cable and Conductor Accessory Manufacturers' Association
- British Approvals Service for Cables
- British Cable Makers' Confederation
- British Plastics Federation
- British Steel Industry
- Department of Trade and Industry (Consumer Safety Unit, CA division)
- Electricity Association
- Engineering Equipment and Materials Users' Association
- Institution of Electrical Engineers
- London Regional Transport

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- ERA Technology Ltd.
- Institution of Incorporated Executive Engineers
- London Underground Ltd.

This British Standard, having been prepared under the direction of the Cables and Insulation Standards Policy Committee was published under the authority of the Standards Board and comes into effect on 15 July 1994

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National foreword

This Section of BS 7769 has been prepared under the direction of the Cables and Insulation Standards Policy Committee. It is identical with IEC 287-1-2:1993 *Electric cables — Calculation of the current rating — Part 1: Current rating equations (100 % load factor) and calculation of losses — Section 2: Sheath eddy current loss factors for two circuits in flat formation*, published by the International Electrotechnical Commission (IEC).

IEC 287 is being revised as a multi-section document under the title *Electric cables — calculation of the current rating*. These will be published as dual-numbered British Standards as they become available.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 22 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This section of IEC 287-1 provides a method for calculating the eddy current losses in the metallic sheaths of single-core cables arranged as a three-phase double circuit in flat formation. The sheaths are bonded at one point or are cross-bonded so that there are no significant sheath circulating currents. Where metallic sheaths are bonded at both ends there are significant circulating currents which result in a lower current-carrying capacity. A method of calculating circulating current losses for double circuits is under consideration.

The method provides coefficients which are applied as corrections to the loss factors for the sheaths of one isolated three-phase circuit. These corrections are negligible for cables where the parameter m is less than about 0,1 ($m = \omega/10^7 R_s$), which corresponds to a sheath longitudinal resistance higher than $314 \mu\Omega/\text{m}$ at 50 Hz.

Consequently the method should be used for most sizes of aluminium-sheathed cables, but is not required for lead-sheathed cables unless they are unusually large:

The coefficients are provided in tabular form and have been computed from fundamental formulae for sheath losses, the evaluation of which calls for expertise in computer programming which might not be readily available in general commercial situations. The development of simplified formulae for some of the tabulated coefficients is under consideration.

Losses for cables in a single circuit will be covered in IEC 287-1-1 (under consideration).

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this section of IEC 287-1. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this section of IEC 287-1 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 287:1982, *Calculation of the continuous current rating of cables (100 % load factor)*.

IEC 287-1-1:199X, *Electric cables — Calculation of the current rating — Part 1: Current rating equations (100 % load factor) and calculation of losses — Section 1: (under consideration)*.

3 Symbols

The symbols used in this section of IEC 287-1 and the quantities they represent are given in the following list. Some of the symbols used in this section may be used to represent different quantities in other section of IEC 287.

A, B, C, D are coefficients used to interpolate for H and J

D_s is the external diameter of the metal sheath (mm)

D_{it} is the diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath (mm)

D_{oc} is the diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath (mm)

G_s is the coefficient which accounts for losses due to eddy currents across the thickness of the sheath due to the current in the conductor

R is the alternating current resistance of the conductor at its maximum operating temperature (Ω/m)

R_s is the resistance of the sheath (Ω/m)

S, T, U, V are the coefficients used to interpolate for J

c is the distance between centres of cables in adjoining circuits (see Figure 1) (mm)

d is the mean diameter of the sheath (mm)

f is the system frequency (Hz)

g_s is the coefficient which accounts for losses due to eddy currents across the thickness of the sheath, due to currents in adjacent cables

m is equal to $\frac{\omega}{R_s} \times 10^{-7}$

s is the distance between centres of cables in the same circuit (mm)

t_s is the thickness of the sheath (mm)

y is equal to $\frac{s}{c}$

z is equal to $\frac{d}{2s}$

β_1 is the coefficient used in 6.5

λ_0 is the sheath loss factor for a high-resistance sheath in a single circuit

λ_1'' is the sheath loss factor for a low-resistance sheath in a single circuit

λ_{1d}'' is the sheath loss factor for a low-resistance sheath in a double circuit

ρ_s is the electrical resistivity of sheath material at operating temperature ($\Omega \cdot m$)

ω is the angular frequency of system ($2\pi f$) (1/s)

4 Description of method

4.1 General

The method proceeds in a way similar to that used for single circuits in IEC 287-1-1. There, formulae for loss factors applicable to sheaths having a longitudinal resistance such that m is less than 0,1 ($R_s = 314 \mu\Omega/m$ at 50 Hz) are given, together with empirical formulae to calculate the correction coefficient for lower resistance sheaths.

However, for double circuits, accurate empirical formulae covering the complete range of coefficients would need to contain so many terms that their use would show little or no advantage over the use of precise, tabulated coefficients with interpolation, as necessary. This latter course has the advantage that the accuracy of the loss factors can be closely equal to that of the original calculations and is better than 1 %.

The development of empirical formulae for a limited range of coefficients is under consideration.

In order to explain the method, it is described here in a way appropriate to manual evaluation of the arithmetic. However, because of the appreciable effort required to provide loss factors for six cables, it is to be expected that calculations will usually be effected by means of a computer. Under these circumstances, the decision to use interpolation (as necessary) between tabulated values is fully justified.

However, in many cases, values of the relevant parameters will be such that interpolation is unnecessary or may be accomplished with sufficient accuracy by inspection.

Corrections to cover the effect of eddy currents circulating within the thickness of a sheath are derived with the use of the same formulae as those used in IEC 287-1-1.

4.2 Outline of method

The loss factor for the sheath of a given cable in a double-circuit flat formation (see Figure 1) is evaluated as follows:

$$\lambda_{1d}'' = \frac{R_s}{R} [\lambda_0 \cdot H(1 \text{ to } 3) \cdot N(1 \text{ to } 6) \cdot J(1 \text{ to } 6) \cdot g_s + G_s] \quad (1)$$

where

λ_{1d}'' is the sheath loss factor for a low-resistance sheath in a double circuit;

λ_0 is the sheath loss factor for a high-resistance sheath in a single circuit;

$H(1 \text{ to } 3)$ are the coefficients which correct for sheath resistance, the values obtained relate to cables 1, 2 or 3 in a single circuit;

$N(1 \text{ to } 6)$ are the coefficients which introduce the mutual influences between circuits and are therefore dependent on the relative phase sequences of cables 1 to 3 and 4 to 6;

$J(1 \text{ to } 6)$ are the coefficients which depend on the cable positions 1 to 3 and 4 to 6 in each circuit;

g_s is the coefficient which accounts for losses due to eddy currents across the thickness of the sheath, due to currents in adjacent cables;

G_s is the coefficient which accounts for losses due to eddy currents across the thickness of the sheath, due to the current in the conductor.

The tasks performed by coefficients N and J are not directly related to any physical function, but have been selected to simplify the tabulation. The nomenclature is arbitrary.

Values of H , N and J are obtained from Table 1 to Table 11 and are chosen according to the following parameters together with the position of the cable and the phase sequence of the currents in the conductors.

$$m = \frac{\omega}{R_s} \times 10^{-7} \quad \omega = 2\pi f$$

where

f is the system frequency (Hz);

R_s is the sheath resistance at operating temperature (Ω/m);

$$z = \frac{d}{2s}$$

where

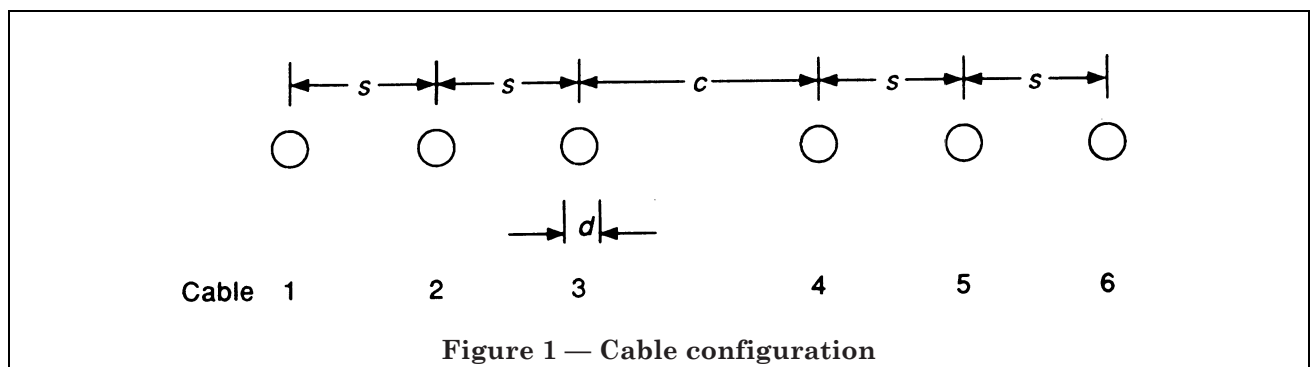
s is the distance between centres of cables in the same circuit (mm);

d is the mean diameter of a sheath (mm);

$$y = \frac{s}{c}$$

where

c is the distance between centres of cables in adjoining circuits (see Figure 1) (mm).



NOTE The factors for a single circuit having low-resistance sheaths can be obtained by using the coefficients H (1, 2 and 3) only, as follows:

$$\lambda'_1 = \frac{R_s}{R} [\lambda_0 \cdot H(1 \text{ to } 3) \cdot g_s + G_s]$$

4.3 Criteria for use of formulae and coefficients

For sheaths for which the value of m is less than 0,1, which includes most lead-sheathed cables, it may be assumed that the coefficients H , N , J and g_s are unity and G_s is zero. In such circumstances, λ_0 may be used for twin circuits without correction.

When the value of m is equal to 0,1 or greater, which is generally the case for all but the smaller aluminium-sheathed cables, values for H , N , J and g_s shall be calculated. The coefficient G_s is important only when the value of m is 1,0 or higher.

5 Formulae for sheath loss factors for high-resistance sheaths in a single circuit, λ_0

The sheath loss factor λ_0 is given by

$$\lambda_0 = C \frac{m^2}{(1 + m^2)} \left[\frac{d}{2s} \right]^2 \quad (2)$$

For three single-core cables in flat formation, the coefficient C is given by:

Cable	Coefficient C
Centre cable	6
Outer cables	1,5

6 Calculation of the coefficients H , N , and J

6.1 Allocation of coefficients to each cable, time sequence and phase identification

It is important to note the way in which the coefficients H , N and J are dependent on the time sequence of the currents and the physical position of the conductors.

The cables shall be numbered according to Figure 1.

The coefficients H (1, 2 and 3), Table 1, are allocated on a basis of time sequence associated with the positions of the cables, so that the following single-circuit arrangements have the same time sequence:

Cable number	1	2	3
Sequence	R	S	T
or	S	T	R
or	T	R	S
with coefficients	H_1	H_2	H_3

In the above example, cable 1 is always the outer conductor on a leading phase and takes coefficient H_1 . Cable 3 is the outer conductor on a lagging phase and takes coefficient H_3 .

It will be seen that, for these cases, the phase identification implied by the symbols R, S and T¹⁾ is not important, it is only the time sequence which is of significance.

In double circuits, if either circuit has a reversed sequence, the values of H must be allocated to the cables in the reverse order. The allocation of coefficient H is dependent on the time sequence within each circuit.

In a double-circuit configuration, the phase identification implied by the symbols is significant to the extent that the phase identification in relation to cable position in one circuit must be either the same as, in the forward sequence, or a mirror image of, in the reverse sequence, that in the other.

Two sets of coefficients N (1, 2, 3, 4, and 6) are given in Table 2 corresponding to the forward and reverse sequences. If the cable positions are labelled sequentially and the phase identification rules are adhered to, the coefficients are allocated on the same basis as coefficient H . Note that the values for cables 4, 5 and 6 in the reversed sequence are a reflection of the values for cables 1, 2 and 3.

The number of input parameters involved for the coefficients J (1, 2, 3, 4, 5 and 6) makes it desirable to use several tables. Table 3 to Table 8 are for each cable for the forward sequence installation. For the reverse sequence, Table 9 to Table 11 are provided and the coefficients for cables 1 to 3 are also used for cables 6 to 4, in that order. The allocation is on the same lines as those for coefficient N .

¹⁾ The letters R, S, T are used here for convenience and are equivalent to other well-known sets of symbols to denote time sequence and phase identification, such as L_1 , L_2 , L_3 ; a, b, c; R, Y, B; etc.

The following tables give examples of four common cases:

Forward sequence

Cable number	1	2	3	4	5	6	
Sequence	R	S	T	R	S	T	
Allocation H	H_1	H_2	H_3	H_1	H_2	H_3	Table 1
Allocation N	N_1	N_2	N_3	N_4	N_5	N_6	Table 2, forward
Allocation J	J_1	J_2	J_3	J_4	J_5	J_6	Table 3 to Table 8, forward

Forward sequence

Cable number	1	2	3	4	5	6	
Sequence	T	S	R	T	S	R	
Allocation H	H_3	H_2	H_1	H_3	H_2	H_1	Table 1
Allocation N	N_6	N_5	N_4	N_3	N_2	N_1	Table 2, forward
Allocation J	J_6	J_5	J_4	J_3	J_2	J_1	Table 3 to Table 8, forward

Reverse sequence

Cable number	1	2	3	4	5	6	
Sequence	R	S	T	T	S	R	
Allocation H	H_1	H_2	H_3	H_3	H_2	H_1	Table 1
Allocation N	N_1	N_2	N_3	N_4	N_5	N_6	Table 2, reverse
Allocation J	J_1	J_2	J_3	J_4	J_5	J_6	Table 9 to Table 11, reverse

Reverse sequence

Cable number	1	2	3	4	5	6	
Sequence	T	S	R	R	S	T	
Allocation H	H_1	H_2	H_3	H_3	H_2	H_1	Table 1
Allocation N	N_1	N_2	N_3	N_4	N_5	N_6	Table 2, reverse
Allocation J	J_1	J_2	J_3	J_4	J_5	J_6	Table 9 to Table 11, reverse

6.2 Calculation of coefficients H (1, 2 and 3), Table 1

Each coefficient H is obtained from Table 1 using the parameters m and z as well as the position of each cable (see 6.1).

When values of m and z involve interpolation between values in Table 1, the following procedure may be used where interpolation by inspection is not desired.

From the relevant part of Table 1, values for H (a, b, c, d) are obtained as shown in the following diagram:

	z_0	z	z_1
m_0	H_a		H_c
m		H	
m_1	H_b		H_d

where m_0 , m_1 , z_0 and z_1 are tabulated values smaller and larger than the values of m and z .