IEC 60287-1-2

Edition 2.0 2023-05

INTERNATIONAL STANDARD

Electric cables – Calculation of the current rating – Part 1-2: Current rating equations (100 % load factor) and calculations of losses – Sheath eddy current loss factors for two circuits in flat formation

IEC 60287-1-2:2023-05(en)

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IEC 60287-1-2 has been prepared by IEC technical committee 20: Electric cables. It is an International Standard.

This second edition cancels and replaces the first edition published in 1993. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the symbols have been harmonized and aligned with the symbols used in the IEC 60287 and IEC 60853 series.

The text of this International Standard is based on the following documents:

Draft	Report on voting
20/2097/FDIS	20/2104/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60287 series, published under the general title *Electric cables – Calculation of the current rating*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 1-2: Current rating equations (100 % load factor) and calculation of losses – Sheath eddy current loss factors for two circuits in flat formation

1 Scope

This part of IEC 60287 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 provided in IEC 60287-1-3.

The method descibed in this document 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 approximately 0,1 ($m = \omega/(R_s \cdot 10^7)$), which corresponds to a sheath longitudinal resistance higher than 314 μΩ/m at 50 Hz.

Consequently, the method is 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 will possibly 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 is covered in IEC 60287-1-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60287-1-1:2023, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*

3 Terms, definitions and symbols

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Symbols

C_{A0}, C_{B0}, C_{C0}, C_{D0}	coefficients used to interpolate for C_H *and* C_J	
C_{H1}, C_{H2}, C_{H3}	coefficients which correct for sheath resistance, the values obtained relate to cables 1, 2 or 3 in a single circuit	
C_{N1}, C_{N2}, C_{N3}, C_{N4}, C_{N5}, C_{N6}	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	
C_{J1}, C_{J2}, C_{J3}, C_{J4}, C_{J5}, C_{J6}	coefficients which depend on the cable positions 1 to 3 and 4 to 6 in each circuit	
$C_{M0,}$ C_{Z0}	coefficients used for calculation of coefficients C_H	
C_S, C_T, C_U, C_V	coefficients used to interpolate for C_J	
C_Y	coefficient used for calculation of coefficients C_J	
$C_{ß1}$	coefficient used for calculation of coefficients G_s and g_s	
D_s	external diameter of the metal sheath	(mm)
D_{it}	the diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath	(mm)
D_{oc}	the diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath	(mm)
G_s	coefficient which accounts for losses due to eddy currents across the thickness of the sheath due to the current in the conductor	
R_c	alternating current resistance of the conductor at its maximum operating temperature	(Ω/m)
R_s	resistance of the sheath	(Ω/m)
c_1	distance between centres of cables in adjoining circuits	(mm)
d	mean diameter of sheath or screen	(mm)
f	system frequency	(Hz)
g_s	coefficient which accounts for losses due to eddy currents across the thickness of the sheath, due to currents in adjacent cables	
m	parameter used in calculation of loss factor	
s	distance between centres of cables in the same circuit	(mm)
t_s	thickness of the sheath	(mm)
y_1	equal to s/c_1	
z	equal to $d/2 \cdot s$	
λ_{0s}	sheath loss factor for a high-resistance sheath in a single circuit	
λ_{1s}''	sheath loss factor for a low-resistance sheath in a single circuit	
λ_{1d}''	sheath loss factor for a low-resistance sheath in a double circuit	
ρ_s	electrical resistivity of sheath material at operating temperature	(Ω · m)
ω	angular frequency of system ($2\pi f$)	(l/s)

4 Description of method

4.1 General

The method proceeds in a way similar to that used for single circuits in IEC 60287-1-1. There, formulae for loss factors applicable to sheaths having a longitudinal resistance such that m is less than 0,1 (R_s = 314 μΩ/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 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 can 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 60287-1-1.

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:

$$\lambda''_{1d} = \frac{R_s}{R_c}\left[\lambda_{0s} \cdot C_H(1 \text{ to } 3) \cdot C_N(1 \text{ to } 6) \cdot C_J(1 \text{ to } 6) \cdot g_s + G_s\right]$$

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

Values of C_H, C_N and C_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.

$$m = \frac{\omega}{R_s} \times 10^{-7}$$

$$\omega = 2\pi f$$

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

$$y_1 = \frac{s}{c_1}$$

where

c_1 is the distance between the centres of cables in adjoining circuits (see Figure 1) (mm).

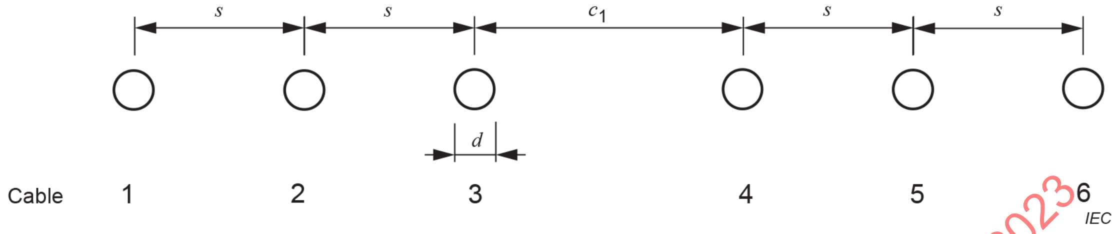

Figure 1 – Cable configuration

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

$$\lambda''_{1s} = \frac{R_s}{R_c}\left[\lambda_{0s} \cdot C_H(1 \text{ to } 3) \cdot g_s + G_s\right]$$

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 can be assumed that the coefficients C_H, C_N, C_J and g_s are unity and G_s is zero. In such circumstances, λ_{0s} can 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 C_H, C_N, C_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_{0s}

The sheath loss factor λ_{0s} is given by

$$\lambda_{0s} = C_{C0}\frac{m^2}{\left(1+m^2\right)}\left[\frac{d}{2s}\right]^2$$

For three single-core cables in flat formation, the coefficient C_{C0} is given by:

Cable	Coefficient C_{C0}
Centre cable	6
Outer cables	1,5

6 Calculation of the coefficients C_H, C_N and C_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 C_H, C_N and C_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 C_{H1}, C_{H2} and C_{H3} of 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	C_{H1}	C_{H2}	C_{H3}

In the above example, cable 1 is always the outer conductor on a leading phase and takes coefficient C_{H1}. Cable 3 is the outer conductor on a lagging phase and takes coefficient C_{H3}.

It will be seen that, for these cases, the phase identification implied by the letters R, S and T 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 C_H shall be allocated to the cables in the reverse order. The allocation of coefficient C_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 the cable position in one circuit shall 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 C_{N1} to C_{N6} 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 C_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 C_{J1} to C_{J6} 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 C_N.

The following tables give examples of four common cases, where letters R, S, T are used for convenience and are equivalent to other well-known sets of symbols to denote time sequence and phase identification, such as L1, L2, L3; a, b, c; R, Y, B.

a) Forward sequence

Cable number	1	2	3	4	5	6	
Sequence	R	S	T	R	S	T	
Allocation C_H	C_{H1}	C_{H2}	C_{H3}	C_{H1}	C_{H2}	C_{H3}	Table 1
Allocation C_N	C_{N1}	C_{N2}	C_{N3}	C_{N4}	C_{N5}	C_{N6}	Table 2, forward
Allocation C_J	C_{J1}	C_{J2}	C_{J3}	C_{J4}	C_{J5}	C_{J6}	Table 3 to Table 8, forward

b) Forward sequence

Cable number	1	2	3	4	5	6	
Sequence	T	S	R	T	S	R	
Allocation C_H	C_{H3}	C_{H2}	C_{H1}	C_{H3}	C_{H2}	C_{H1}	Table 1
Allocation C_N	C_{N6}	C_{N5}	C_{N4}	C_{N3}	C_{N2}	C_{N1}	Table 2, forward
Allocation C_J	C_{J6}	C_{J5}	C_{J4}	C_{J3}	C_{J2}	C_{J1}	Table 3 to Table 8, forward

c) Reverse sequence

Cable number	1	2	3	4	5	6	
Sequence	R	S	T	T	S	R	
Allocation C_H	C_{H1}	C_{H2}	C_{H3}	C_{H3}	C_{H2}	C_{H1}	Table 1
Allocation C_N	C_{N1}	C_{N2}	C_{N2}	C_{N4}	C_{N5}	C_{N6}	Table 2, forward
Allocation C_J	C_{J1}	C_{J2}	C_{J3}	C_{J4}	C_{J5}	C_{J6}	Table 9 to Table 11, forward

d) Reverse sequence

Cable number	1	2	3	4	5	6	
Sequence	T	S	R	R	S	T	
Allocation C_H	C_{H1}	C_{H2}	C_{H3}	C_{H3}	C_{H2}	C_{H1}	Table 1
Allocation C_N	C_{N6}	C_{N5}	C_{N4}	C_{N3}	C_{N2}	C_{N1}	Table 2, forward
Allocation C_J	C_{J6}	C_{J5}	C_{J4}	C_{J3}	C_{J2}	C_{J1}	Table 9 to Table 11, forward

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

Each coefficient C_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 should be used where interpolation by inspection is not desired.

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

	z_0	z	z_1
m_0	C_{Ha}		C_{Hc}
m		C_H	
m_1	C_{Hb}		C_{Hd}

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

Tabulate:

m_0 ....

m_1 .... $C_{M0} = (m_1 - m_0)$ ....

z_0 ....

z_1 .... $C_{Z0} = (z_1 - z_0)$ ....

C_{Ha} ....

C_{Hb} ....

C_{Hc} ....

C_{Hd} ....

Then:

$C_A = C_{Ha}$ = ...

$C_B = (C_{Hb} - C_{Ha})/C_{M0}$ = ...

$C_C = (C_{Hc} - C_{Ha})/C_{Z0}$ = ...

$C_D = (C_{Hd} + C_{Ha} - C_{Hc} - C_{Hb})/C_{M0} \cdot C_{Z0}$ = ...

Add together:

C_A = ...

$+C_B \cdot (m - m_0)$ = ...

$+C_C \cdot (z - z_0)$ = ...

$+C_D \cdot (m - m_0) \cdot (z - z_0)$ = ...

Coefficient C_H = total = ...

This process shall be repeated for each of the three cables in a circuit to obtain C_{H1}, C_{H2} and C_{H3}.

6.3 Calculation of coefficients C_N (1, 2, 3, 4, 5 and 6), Table 2

Values of coefficient C_N are obtained from Table 2, using parameter y for each cable. The table has values for the forward and reverse sequences. Note that in the latter case the coefficients for cables 4, 5 and 6 form a mirror image of those for cables 1 to 3.

Where interpolation is required, a linear one-dimensional interpolation is adequate.

6.4 Calculation of coefficients C_J (1, 2, 3, 4, 5 and 6), Table 3 to Table 11

Values of coefficient C_J for each cable are obtained from Table 3 to Table 11, according to the sequence of the currents and the parameters m, z and y_1.

Table 3 to Table 8 apply to the six cables when the currents in the conductors follow the forward sequence. But, in a reversed sequence, Table 9 to Table 11 apply to cables 1 to 3 and also to cables 6 to 4, in that order.

Interpolation between all three input parameters can be necessary and the following scheme for a three-dimensional interpolation can be used.

The tables for each cable are arranged in groups, one for each value of the parameter y_1. Two groups can be chosen, one for a value of y_1 smaller, and one for a value larger, than the input value. For each group, values of C_J (a to d) and C_J (e to f) are required (in a similar way to the interpolation for C_H), as shown in the following diagrams.

	z_0	z	z_1
m_0	C_{Ja}		C_{Jc}
m		*	
m_1	C_{Jb}		C_{Jd}

Group for y_0

	z_0	z	z_1
m_0	C_{Je}		C_{Jg}
m		*	
m_1	C_{Jf}		C_{Jh}

Group for y_1

Interpolation between the values marked * gives the required value of J for each cable.

The arithmetic should be tabulated as follows:

y_0..........................	z_0..........................	m_0..............................	C_{Ja}..................
		m_1..............................	C_{Jb}..................
	z_1..........................	m_0..............................	C_{Jc}..................
		m_1..............................	C_{Jd}..................
y_1..........................	z_0..........................	m_0..............................	C_{Je}..................
		m_1..............................	C_{Jf}..................
	z_1..........................	m_0..............................	C_{Jg}..................
		m_1..............................	C_{Jh}..................

$C_{M0} = (m_1 - m_0)$....................... $C_{Z0} = (z_1 - z_0)$.................... $C_Y = (y_1 - y_0)$...........

$m' = (m - m_0)$......................... $z' = (z - z_0)$......................... $y' = (y - y_0)$................

Calculate:

$C_A = C_{Ja}$ =.............................

$C_B = (C_{Jb} - C_{Ja}) / C_{M0}$ =.............................

$C_C = (C_{Jc} - C_{Ja}) / C_{Z0}$ =.............................

$C_D = (C_{Je} - C_{Ja}) / C_Y$ =.............................

$C_S = [(C_{Ja} + C_{Jd}) - (C_{Jb} + C_{Jc})] / C_{M0} \cdot C_{Z0}$ =............................

$C_T = [(C_{Ja} + C_{Jg}) - (C_{Jc} + C_{Je})] / C_{Z0} \cdot C_Y$ =............................

$C_U = [(C_{Ja} + C_{Jf}) - (C_{Jb} + C_{Je})] / C_{M0} \cdot C_Y$ =............................

$C_V = [(C_{Jb} + C_{Jc} + C_{Je} + C_{Jh}) - (C_{Ja} + C_{Jd} + C_{Jf} + C_{Jg})] / C_{M0} \cdot C_{Z0} \cdot C_Y$ =............................

Then add up the following:

C_A =......................

$C_B \cdot m'$ =......................

$C_C \cdot z'$ =......................

$C_D \cdot y'$ =......................

$C_S \cdot m' \cdot z'$ =......................

$C_T \cdot z' \cdot y'$ =......................

$C_U \cdot m' \cdot y'$ =......................

$C_V \cdot m' \cdot z' \cdot y'$ =......................

C_J = total =......................

Values of C_J for each of the other five cables are found in the same way.

6.5 Calculation of coefficients G_s and g_s

$$G_s = \frac{(C_{\beta 1} \cdot t_s)^4}{12 \times 10^{12}}$$

$$C_{\beta 1} = \sqrt{\frac{4\pi\omega}{10^7 \cdot \rho_s}}$$

$$g_s = 1 + \left[\frac{t_s}{D_s}\right]^{1,74} \cdot \left(C_{\beta 1} \cdot D_s \cdot 10^{-3} - 1,6\right)$$

For corrugated sheaths, the mean outside diameter $\frac{D_{OC} + D_{it}}{2} + t_s$ shall be used in place of D_s.

7 Notes on transposition of cables

The general effect of transposition is to rotate either all of the conductors or all of the sheaths, or both, progressively from sub-section to sub-section. Such changes do not affect the sequence of the conductor currents and, provided that the transpositions in each circuit are effected in the same way with respect to the phase sequence (that is, the requirements for time sequence and sheath position given in 6.1 are observed in the same way for all sub-sections), transposition will not affect the application.

Transposition can take place either in the same direction or in the opposite direction to that of the phase sequence. The direction does not affect the eddy current losses, provided that for both circuits the direction at each transposition, relative to the phase sequence, is the same. It follows that, if the circuits have reversed conductor current sequences, the physical direction of transposition in one circuit will be opposite to that in the other.

Values of sheath eddy current losses are dependent only on position in the cable arrangement and, once calculated, apply to any sheath in a certain position, irrespective of the sub-section.

8 Worked examples of calculation of eddy current losses

8.1 Overview

The cable dimensions used in the following examples are arbitrary and do not represent any particular type of cable.

In many cases there is no need for interpolation, or the parameters use parts of the tables where interpolation by inspection is adequate.

However, where the intervals in the tables are too large for interpolation by inspection or when calculation is made by computer, the interpolation routines are useful and are not difficult to use manually or to program on a computer.

8.2 Example 1

In this example, the installation parameters coincide with entries in the tables and no interpolation is needed.

Let:

the mean diameter of the sheath	d = 90 mm
aluminium sheath thickness	t_s = 3,18 mm
sheath resistance	$R_s = 62{,}9 \cdot 10^{-6}$ Ω/m
conductor resistance	$R_c = 11{,}3 \cdot 10^{-6}$ Ω/m
sheath resistivity	$\rho_s = 2{,}826\,4 \cdot 10^{-8}$ Ω · m
(see IEC 60287-1-1:2023, Table 1)	
distance between centres of cables within circuits	s = 150 mm
between circuits	c_1 = 375 mm

then:

$$m = \frac{314 \cdot 10^{-7}}{62{,}9 \cdot 10^{-6}} = 0{,}5$$

$$z = \frac{90}{2 \cdot 150} = 0{,}3$$

$$y = \frac{150}{375} = 0{,}4$$

$$\frac{R_S}{R_C} = \frac{62{,}9 \cdot 10^{-6}}{11{,}3 \cdot 10^{-6}} = 5{,}57$$

$$\lambda_{os} = C_C \cdot \frac{0{,}5^2}{1+0{,}5^2}\left[\frac{90}{300}\right]^2 = C_C \cdot 0{,}0180$$

Corrections for thickness:

$$C_{\beta 1} = \sqrt{\frac{4 \cdot \pi \cdot 314}{2{,}8264 \cdot 10^{-8} \cdot 10^7}} = 118{,}2$$

$$g_s = 1 + \left[\frac{3{,}18}{93{,}18}\right]^{1{,}74} \left(118{,}2 \cdot 93{,}18 \cdot 10^{-3} - 1{,}6\right) = 1{,}026$$

$$G_s = \frac{(118{,}2 \cdot 3{,}18)^4}{12 \cdot 10^{12}} = 0{,}0017$$

Assume conductors are connected in a reversed sequence.

Cable	1	2	3	4	5	6
Sequence	R	S	T	T	S	R
C_C	1,5	6,0	1,5	1,5	6,0	1,5
λ_{0s}	0,027 0	0,108 0	0,027 0	0,027 0	0,108 0	0,027 0
C_H (m = 0,5 z = 0,3)	1,220 0	1,025 0	0,919 0	0,919 0	1,025 0	1,220 0
C_N (y = 0,4)	1,060 5	1,106 6	1,259 3	1,259 3	1,106 6	1,060 5
C_J (m = 0,5 z = 0,3 y = 0,4)	1,010 0	1,000 0	0,965 0	0,965 0	1,000 0	1,010 0
g_s	1,026	1,026	1,026	1,026	1,026	1,026
G_s	0,001 7	0,001 7	0,001 7	0,001 7	0,001 7	0,001 7
R_s/R_c	5,57	5,57	5,57	5,57	5,57	5,57

Substitute these quantities in λ''_{1d} of 4.2

λ''_{1d}	0,021 1	0,710	0,182	0,182	0,710	0,021 1

For cable 1, the arithmetic is:

λ''_{1d} = 5,57 [(0,027 0 · 1,220 0 · 1,060 5 · 1,010 0 · 1,026 0) + 0,001 7] = 0,211

8.3 Example 2

In this example, the arbitrary parameters have been selected so that interpolation between tabulated values is required.

Let:

the mean diameter of the sheath	d = 100 mm
aluminium sheath thickness	t_s = 2,6 mm
sheath resistance	$R_s = 35 \cdot 10^{-6}$ Ω/m
conductor resistance	$R_c = 9 \cdot 10^{-6}$ Ω/m
sheath resistivity	$\rho_s = 2{,}826\,4 \cdot 10^{-8}$ Ω · m
(see IEC 60287-1-1:2023, Table 1).	
distance between centres of cables within circuits	s = 150 mm
between circuits	c_1 = 400 mm

then:

$$m = \frac{314 \cdot 10^{-7}}{35 \cdot 10^{-6}} = 0{,}897$$

$$z = \frac{100}{2 \cdot 150} = 0{,}333$$

$$y_1 = \frac{150}{400} = 0{,}375$$

$$\lambda_{os} = C_C \cdot \frac{0{,}897^2}{1 + 0{,}897^2}\left[\frac{100}{2 \cdot 150}\right]^2 = C_C \cdot 0{,}0495$$

$$\frac{R_S}{R_C} = \frac{35 \cdot 10^{-6}}{9 \cdot 10^{-6}} = 3{,}89$$

Take cable number 1, and a forward sequence of currents:

$$C_C = 1{,}5 \qquad \lambda_{0S} = 1{,}5 \cdot 0{,}0495 = 0{,}0743$$

$$C_{\beta 1} = \sqrt{\frac{4 \cdot \pi \cdot 314}{2{,}8264 \cdot 10^{-8} \cdot 10^7}} = 118{,}2$$

$$g_s = 1 + \left[\frac{1{,}6}{102{,}6}\right]^{1{,}74} \left(118{,}2 \cdot 102{,}6 \cdot 10^{-3} - 1{,}6\right) = 1{,}018$$

$$G_s = \frac{(118{,}2 \cdot 2{,}6)^4}{12 \cdot 10^{12}} = 0{,}0007$$

a) interpolate for C_H:

m = 0,897 z = 0,333

from the table of C_H coefficients:

m_0 = 0,500

m_1 = 1,000 $C_{M0} = (m_1 - m_0)$ = 0,500

z_0 = 0,300

z_1 = 0,350 $C_{Z0} = (z_1 - z_0)$ = 0,050

$(m - m_0)$ = (0,897 – 0,500) = 0,397

$(z - z_0)$ = (0,333 – 0,300) = 0,033

C_{Ha} = 1,220

C_{Hb} = 1,347

C_{Hc} = 1,309

C_{Hd} = 1,503

C_A = 1,220

C_B = (1,347 – 1,220)/0,5 = 0,254

C_C = (1,309 – 1,220)/0,005 = 1,780

C_D = (1,503 + 1,220 – 1,309 – 1,347)/(0,5 · 0,05) = 2,680

Add together:

C_A = 1,220 0

$C_B \cdot (m - m_0)$ = 0,254 · 0,397 = 0,100 8

$C_C \cdot (z - z_0)$ = 1,780 · 0,033 = 0,058 7

$C_D \cdot (m - m_0) \cdot (z - z_0)$ = 2,68 · 0,397 · 0,033 = 0,035 1

$C_H = C_A + C_B + C_C + C_D$ = 1,220 0 + 0,100 8 + 0,058 7 + 0,035 1 = 1,414 6

b) interpolate for C_N:

y = 0,375

from the table of C_N coefficients:

y_0 = 0,3 y_1 = 0,4

$(y - y_0)$ = 0,375 – 0,3 = 0,075

C_{Na} = 0,943 2 C_{Nb} = 0,923 8

C_N = 0,943 2 + [(0,923 8 – 0,943 2) / (0,4 – 0,3)] · 0,075 = 0,929

c) interpolate for C_J:

m = 0,897	z = 0,333	y = 0,375	
y_0 = 0,200	z_0 = 0,300	m_0 = 0,500	C_{Ja} = 0,995
		m_1 = 1,000	C_{Jb} = 0,992
	z_1 = 0,400		C_{Jc} = 0,991
			C_{Jd} = 0,984
y_1 = 0,400			C_{Je} = 0,991
			C_{Jf} = 0,983
			C_{Jg} = 0,982
			C_{Jh} = 0,964
C_{M0} = 0,5	C_{Z0} = 0,1	C_Y = 0,2	
m' = 0,397	z' = 0,033	y' = 0,175	

C_A =	0,995
C_B = (0,992 – 0,995) / 0,5 =	-0,006
C_C = (0,991 – 0,995) / 0,1 =	-0,040
C_D = (0,991 – 0,995) / 0,2 =	-0,020
C_Q = [(0,995 + 0,984) – (0,992 + 0,991)] / (0,5 · 0,1) =	-0,080
C_R = [(0,995 + 0,982) – (0,991 + 0,991)] / (0,1 · 0,2) =	-0,250
C_S = [(0,995 + 0,983) – (0,992 + 0,991)] / (0,5 · 0,2) =	-0,050
C_T = [(0,992 + 0,991 + 0,991 + 0,964) – (0,995 + 0,984 + 0,983 + 0,982)] / (0,5 · 0,1 · 0,2) =	-0,600

Add together:

C_A =	0,995 0
$C_B \cdot m'$ = – 0,006 · 0,397 =	–0,002 4
$C_C \cdot z'$ = – 0,04 · 0,033 =	–0,001 3
$C_D \cdot y'$ = – 0,02 · 0,175 =	–0,003 5
$C_Q \cdot m' \cdot z'$ = – 0,080 · 0,397 · 0,033 =	–0,001 1
$C_R \cdot z' \cdot y'$ = – 0,25 · 0,033 · 0,175 =	–0,001 4
$C_S \cdot m' \cdot y'$ = – 0,05 · 0,397 · 0,175 =	–0,003 5
$C_T \cdot m' \cdot z' \cdot y'$ = – 0,6 · 0,397 · 0,033 · 0,175 =	–0,001 4

$$C_J = C_A + C_B \cdot m' + C_C \cdot z' + C_D \cdot y' + C_Q \cdot m' \cdot z' + C_R \cdot z' \cdot y' + C_S \cdot m' \cdot y' + C_T \cdot m' \cdot z' \cdot y'$$

$$C_J = 0{,}995\,0 - 0{,}002\,4 - 0{,}001\,3 - 0{,}003\,5 - 0{,}001\,1 - 0{,}001\,4 - 0{,}003\,5 - 0{,}001\,4$$

C_J = 0,980 4

Substitution in λ''_{1d} of 4.2 gives:

$$\lambda_{1d}'' = 3{,}89\,[(0{,}074\,3 \cdot 1{,}414\,6 \cdot 0{,}929 \cdot 0{,}980\,4 \cdot 1{,}018) + 0{,}000\,7] = 0{,}382$$

A summary of the sheath loss factors for all six cables, together with the corresponding factors for smaller values of the circuit separation c and for a single-circuit installation (corresponding to a very large circuit spacing) are as follows:

Spacing c_1	150	300	400	Single circuit
mm				
Cable n°	Sheath loss factors			
1	0,346	0,373	0,382	0,419
2	0,955	1,100	1,151	1,262
3	0,274	0,250	0,256	0,276
4	0,402	0,336	0,356	0,419
5	0,943	1,094	1,142	1,262
6	0,230	0,251	0,258	0,276

Table 1 – C_H coefficients

	m	0,1	0,15	0,20	0,25	0,30	0,35	0,40	0,45	0,50
Cable 1	0,1	1,007	1,015	1,028	1,044	1,064	1,089	1,118	1,154	1,197
	0,5	1,023	1,051	1,093	1,148	1,220	1,309	1,420	1,554	1,714
	1,0	1,033	1,076	1,140	1,228	1,347	1,503	1,706	1,970	2,299
	1,5	1,037	1,085	1,158	1,261	1,405	1,606	1,887	2,284	2,826
	2,0	1,037	1,087	1,163	1,274	1,432	1,662	2,003	2,527	3,321
	2,5	1,037	1,087	1,164	1,278	1,444	1,693	2,081	2,720	3,792
	3,0	1,037	1,087	1,164	1,279	1,449	1,711	2,135	2,876	4,244
Cable 2	0,1	1,001	1,002	1,004	1,006	1,009	1,013	1,017	1,022	1,028
	0,5	1,003	1,007	1,012	1,018	1,025	1,033	1,040	1,047	1,050
	1,0	1,006	1,015	1,027	1,043	1,064	1,090	1,121	1,157	1,193
	1,5	1,009	1,021	1,039	1,065	1,101	1,150	1,218	1,306	1,413
	2,0	1,010	1,025	1,047	1,080	1,128	1,198	1,301	1,450	1,654
	2,5	1,011	1,027	1,052	1,091	1,148	1,234	1,366	1,575	1,892
	3,0	1,012	1,029	1,056	1,098	1,161	1,260	1,417	1,681	2,123
Cable 3	0,1	0,999	0,998	0,996	0,994	0,991	0,988	0,984	0,979	0,973
	0,5	0,991	0,980	0,964	0,944	0,919	0,889	0,853	0,812	0,766
	1,0	0,994	0,986	0,975	0,962	0,947	0,931	0,915	0,900	0,891
	1,5	1,000	1,001	1,002	1,007	1,017	1,036	1,068	1,124	1,214
	2,0	1,006	1,013	1,027	1,048	1,082	1,137	1,226	1,374	1,608
	2,5	1,010	1,023	1,045	1,080	1,134	1,220	1,364	1,608	2,017
	3,0	1,013	1,031	1,060	1,104	1,174	1,287	1,477	1,816	2,422

Table 2 – C_N coefficients

Cable forward						
$y_1 = s/c_1$	**1**	**2**	**3**	**4**	**5**	**6**
0,1	0,987 1	0,986 1	0,985 4	0,984 9	0,986 1	0,987 5
0,2	0,965 1	0,958 8	0,956 2	0,955 4	0,958 8	0,965 6
0,3	0,943 2	0,928 6	0,927 1	0,925 9	0,928 6	0,943 8
0,4	0,923 8	0,899 0	0,906 5	0,904 9	0,899 0	0,924 3
0,5	0,906 9	0,871 4	0,899 3	0,897 4	0,871 3	0,907 5
0,6	0,892 4	0,846 1	0,908 9	0,906 7	0,846 1	0,892 9
0,7	0,880 0	0,823 2	0,937 2	0,935 1	0,823 1	0,880 4
0,8	0,869 2	0,802 4	0,985 9	0,984 2	0,802 3	0,869 6
0,9	0,859 8	0,783 6	1,056 2	1,055 2	0,783 5	0,860 1
1,0	0,851 6	0,766 5	1,148 7	1,149 0	0,766 5	0,851 7
Cable reverse						
$y_1 = s/c_1$	**1**	**2**	**3**	**4**	**5**	**6**
0,1	1,011 0	1,014 1	1,018 5	1,018 5	1,014 1	1,011 0
0,2	1,028 6	1,042 1	1,069 6	1,069 6	1,042 1	1,028 6
0,3	1,045 6	1,074 2	1,150 4	1,150 4	1,074 2	1,045 6
0,4	1,060 5	1,106 6	1,259 3	1,259 3	1,106 6	1,060 5
0,5	1,073 6	1,137 8	1,395 3	1,395 3	1,137 8	1,073 6
0,6	1,084 9	1,167 3	1,558 0	1,558 0	1,167 3	1,084 9
0,7	1,094 8	1,194 8	1,747 1	1,747 1	1,194 8	1,094 8
0,8	1,103 5	1,220 4	1,962 3	1,962 3	1,220 4	1,103 5
0,9	1,111 1	1,244 1	2,203 7	2,203 7	1,244 1	1,111 1
1,0	1,118 0	1,266 2	2,471 1	2,471 1	1,266 2	1,118 0

Table 3 – C_J coefficients

		Cable 1 / Forward $z = d/2s$				
$y_1 = s/c_1$	m	**0,1**	**0,2**	**0,3**	**0,4**	**0,5**
0,2	0,1	1,000	1,000	1,000	1,000	1,000
	0,5	1,000	0,998	0,995	0,991	0,982
	1,0	0,999	0,997	0,992	0,984	0,970
	1,5	1,000	0,997	0,992	0,984	0,974
	2,0	0,999	0,997	0,992	0,987	0,980
	2,5	0,999	0,997	0,994	0,989	0,987
	3,0	1,000	0,997	0,994	0,992	0,993
0,4	0,1	1,000	1,000	1,000	1,000	1,000
	0,5	0,999	0,997	0,991	0,982	0,965
	1,0	0,999	0,994	0,983	0,964	0,931
	1,5	0,999	0,992	0,981	0,962	0,933
	2,0	0,998	0,992	0,982	0,966	0,946
	2,5	0,998	0,992	0,983	0,971	0,959
	3,0	0,999	0,993	0,984	0,975	0,971
0,6	0,1	1,000	1,000	1,001	1,001	1,002
	0,5	0,999	0,996	0,990	0,978	0,955
	1,0	0,998	0,991	0,977	0,949	0,900
	1,5	0,998	0,989	0,972	0,942	0,894
	2,0	0,997	0,989	0,972	0,945	0,907
	2,5	0,997	0,988	0,973	0,951	0,925
	3,0	0,998	0,989	0,974	0,956	0,941
0,8	0,1	1,000	1,001	1,002	1,003	1,004
	0,5	0,999	0,996	0,990	0,978	0,955
	1,0	0,998	0,990	0,974	0,941	0,881
	1,5	0,997	0,987	0,966	0,927	0,860
	2,0	0,996	0,985	0,963	0,927	0,869
	2,5	0,996	0,985	0,963	0,931	0,886
	3,0	0,996	0,985	0,964	0,937	0,904
1,0	0,1	1,000	1,001	1,003	1,005	1,007
	0,5	0,999	0,997	0,992	0,983	0,962
	1,0	0,998	0,990	0,973	0,939	0,877
	1,5	0,997	0,985	0,962	0,918	0,842
	2,0	0,995	0,983	0,957	0,913	0,840
	2,5	0,995	0,982	0,956	0,915	0,852
	3,0	0,996	0,981	0,956	0,919	0,866

Table 4 – C_J coefficients

$y_1 = s/c_1$	m	Cable 2 / Forward $z = d/2s$				
		0,1	**0,2**	**0,3**	**0,4**	**0,5**
0,2	0,1	1,000	1,000	1,000	1,001	1,001
	0,5	1,000	1,000	1,000	1,000	1,000
	1,0	1,000	1,000	1,001	1,001	1,002
	1,5	1,000	1,000	1,001	1,003	1,006
	2,0	1,000	1,001	1,002	1,005	1,011
	2,5	1,000	1,001	1,002	1,007	1,014
	3,0	1,000	1,001	1,003	1,008	1,018
0,4	0,1	1,000	1,001	1,001	1,002	1,003
	0,5	1,000	1,000	1,000	1,000	1,000
	1,0	1,000	1,000	1,000	1,002	1,003
	1,5	1,000	1,000	1,002	1,007	1,014
	2,0	1,000	1,000	1,003	1,011	1,026
	2,5	1,000	1,000	1,004	1,015	1,036
	3,0	1,000	1,000	1,005	1,017	1,043
0,6	0,1	1,000	1,001	1,002	1,003	1,006
	0,5	0,999	0,999	0,999	0,999	0,998
	1,0	0,999	0,998	0,998	0,999	1,000
	1,5	0,999	0,998	0,999	1,005	1,016
	2,0	0,999	0,998	1,001	1,012	1,034
	2,5	0,999	0,998	1,002	1,018	1,049
	3,0	0,999	0,998	1,003	1,022	1,062
0,8	0,1	1,000	1,001	1,002	1,004	1,008
	0,5	0,999	0,999	0,998	0,996	0,995
	1,0	0,999	0,996	0,993	0,992	0,991
	1,5	0,998	0,995	0,993	0,998	1,007
	2,0	0,998	0,995	0,994	1,006	1,029
	2,5	0,998	0,995	0,996	1,013	1,049
	3,0	0,998	0,994	0,997	1,017	1,065
1,0	0,1	1,000	1,001	1,003	1,006	1,010
	0,5	0,999	0,997	0,995	0,993	0,993
	1,0	0,998	0,992	0,987	0,982	0,978
	1,5	0,997	0,990	0,984	0,984	0,988
	2,0	0,996	0,989	0,984	0,991	1,006
	2,5	0,996	0,989	0,985	0,997	1,027
	3,0	0,996	0,988	0,986	1,002	1,044

Table 5 – C_J coefficients

		Cable 3 / Forward $z = d/2s$				
$y_1 = s/c_1$	*m*	**0,1**	**0,2**	**0,3**	**0,4**	**0,5**
0,2	0,1	1,000	1,001	1,003	1,005	1,008
	0,5	1,000	1,003	1,007	1,012	1,017
	1,0	1,000	1,002	1,007	1,014	1,022
	1,5	1,000	1,001	1,006	1,014	1,025
	2,0	0,999	1,001	1,005	1,014	1,028
	2,5	1,000	1,000	1,003	1,014	1,030
	3,0	0,999	0,999	1,003	1,013	1,032
0,4	0,1	1,000	1,003	1,007	1,013	1,021
	0,5	1,001	1,006	1,015	1,028	1,041
	1,0	0,999	1,002	1,011	1,026	1,047
	1,5	0,998	0,997	1,005	1,023	1,053
	2,0	0,997	0,994	1,000	1,021	1,058
	2,5	0,996	0,992	0,995	1,018	1,063
	3,0	0,995	0,990	0,993	1,016	1,067
0,6	0,1	1,000	1,003	1,009	1,017	1,026
	0,5	0,999	1,003	1,010	1,021	1,033
	1,0	0,995	0,990	0,990	1,002	1,024
	1,5	0,992	0,978	0,973	0,989	1,026
	2,0	0,989	0,971	0,962	0,980	1,031
	2,5	0,988	0,966	0,954	0,974	1,037
	3,0	0,987	0,963	0,948	0,969	1,042
0,8	0,1	1,000	1,003	1,007	1,012	1,018
	0,5	0,996	0,990	0,982	0,977	0,972
	1,0	0,988	0,962	0,937	0,927	0,933
	1,5	0,983	0,943	0,908	0,901	0,925
	2,0	0,979	0,932	0,891	0,886	0,929
	2,5	0,977	0,925	0,879	0,876	0,934
	3,0	0,975	0,921	0,872	0,869	0,939
1,0	0,1	1,000	1,001	1,002	1,003	1,002
	0,5	0,990	0,968	0,936	0,900	0,863
	1,0	0,978	0,925	0,864	0,816	0,790
	1,5	0,971	0,901	0,826	0,781	0,778
	2,0	0,967	0,888	0,806	0,765	0,783
	2,5	0,965	0,882	0,796	0,756	0,790
	3,0	0,963	0,877	0,790	0,751	0,797

Table 6 – C_J coefficients

		Cable 4 / Forward $z = d/2s$				
$y_1 = s/c_1$	m	0,1	0,2	0,3	0,4	0,5
0,2	0,1	1,000	1,000	0,999	0,998	0,997
	0,5	0,999	0,995	0,989	0,979	0,963
	1,0	0,998	0,993	0,982	0,967	0,946
	1,5	0,999	0,992	0,983	0,970	0,956
	2,0	0,998	0,993	0,984	0,976	0,968
	2,5	0,998	0,993	0,986	0,981	0,979
	3,0	0,999	0,994	0,988	0,985	0,988
0,4	0,1	1,000	0,999	0,997	0,994	0,990
	0,5	0,997	0,984	0,962	0,929	0,881
	1,0	0,994	0,973	0,936	0,884	0,819
	1,5	0,993	0,969	0,933	0,888	0,841
	2,0	0,992	0,970	0,937	0,903	0,876
	2,5	0,992	0,971	0,942	0,919	0,906
	3,0	0,993	0,972	0,947	0,930	0,929
0,6	0,1	1,000	0,998	0,995	0,991	0,987
	0,5	0,994	0,972	0,934	0,879	0,807
	1,0	0,987	0,946	0,878	0,782	0,671
	1,5	0,985	0,937	0,863	0,772	0,685
	2,0	0,983	0,935	0,864	0,790	0,732
	2,5	0,983	0,935	0,870	0,811	0,775
	3,0	0,984	0,936	0,875	0,828	0,809
0,8	0,1	1,000	0,999	0,998	0,999	1,003
	0,5	0,992	0,966	0,924	0,869	0,809
	1,0	0,982	0,926	0,836	0,716	0,596
	1,5	0,977	0,907	0,801	0,675	0,566
	2,0	0,974	0,900	0,793	0,681	0,595
	2,5	0,973	0,897	0,795	0,697	0,630
	3,0	0,973	0,897	0,799	0,713	0,662
1,0	0,1	1,000	1,003	1,011	1,026	1,053
	0,5	0,993	0,974	0,949	0,929	0,947
	1,0	0,980	0,924	0,839	0,743	0,698
	1,5	0,972	0,896	0,784	0,664	0,602
	2,0	0,968	0,882	0,764	0,647	0,585
	2,5	0,965	0,875	0,758	0,650	0,591
	3,0	0,964	0,873	0,757	0,657	0,602

Table 7 – C_J coefficients

		Cable 5 / Forward $z = d/2s$				
$y_1 = s/c_1$	m	**0,1**	**0,2**	**0,3**	**0,4**	**0,5**
0,2	0,1	1,000	1,000	1,001	1,001	1,002
	0,5	0,999	0,999	0,999	0,997	0,994
	1,0	1,000	0,999	0,998	0,996	0,989
	1,5	1,000	0,999	0,999	1,000	0,997
	2,0	1,000	0,999	1,000	1,004	1,007
	2,5	1,000	1,000	1,002	1,008	1,017
	3,0	1,000	1,000	1,003	1,011	1,025
0,4	0,1	1,000	1,000	1,001	1,001	1,002
	0,5	0,999	0,999	0,999	0,997	0,994
	1,0	1,000	0,999	0,998	0,996	0,989
	1,5	1,000	0,999	0,999	1,000	0,997
	2,0	1,000	0,999	1,000	1,004	1,007
	2,5	1,000	1,000	1,002	1,008	1,017
	3,0	1,000	1,000	1,003	1,011	1,025
0,6	0,1	1,000	1,001	1,001	1,002	1,004
	0,5	0,999	0,999	0,997	0,993	0,986
	1,0	0,999	0,997	0,993	0,986	0,972
	1,5	0,999	0,997	0,994	0,991	0,980
	2,0	0,999	0,997	0,996	0,998	0,995
	2,5	0,999	0,997	0,997	1,004	1,011
	3,0	0,999	0,997	0,999	1,009	1,025
0,8	0,1	1,000	1,001	1,002	1,003	1,006
	0,5	0,999	0,998	0,994	0,987	0,976
	1,0	0,998	0,994	0,986	0,973	0,948
	1,5	0,998	0,993	0,985	0,976	0,952
	2,0	0,998	0,993	0,987	0,983	0,970
	2,5	0,998	0,993	0,989	0,991	0,990
	3,0	0,997	0,993	0,991	0,997	1,008
1,0	0,1	1,000	1,001	1,002	1,004	1,007
	0,5	0,998	0,996	0,991	0,982	0,968
	1,0	0,997	0,990	0,978	0,957	0,923
	1,5	0,996	0,987	0,974	0,955	0,919
	2,0	0,996	0,987	0,974	0,961	0,933
	2,5	0,996	0,987	0,976	0,969	0,952
	3,0	0,996	0,986	0,977	0,976	0,970