IEC 60287-1-3

Edition 2.0 2023-05

INTERNATIONAL STANDARD

Electric cables – Calculation of the current rating –
Part 1-3: Current rating equations (100 % load factor) and calculation of losses – Current sharing between parallel single-core cables and calculation of circulating current losses

IEC 60287-1-3:2023-05(en)

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC 60287-1-3

Edition 2.0 2023-05

INTERNATIONAL STANDARD

Electric cables – Calculation of the current rating – Part 1-3: Current rating equations (100 % load factor) and calculation of losses – Current sharing between parallel single-core cables and calculation of circulating current losses

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 29.060.20

ISBN 978-2-8322-6973-2

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 1-3: Current rating equations (100 % load factor) and calculation of losses – Current sharing between parallel single-core cables and calculation of circulating current losses

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 60287-1-3 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 2002. This edition constitutes a technical revision.

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

a) Change and update of list of symbols.

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

Draft	Report on voting
20/2098/FDIS	20/2105/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.

INTRODUCTION

When single-core cables are installed in parallel, it is possible that the load current will not share equally between the parallel cables. The circulating currents in the sheaths of the parallel cables will also differ. This is because a significant proportion of the impedance of large conductors is due to self reactance and mutual reactance. Hence the spacing and relative location of each cable will have an effect on the current sharing and the circulating currents. The currents are also affected by phase rotation. The method described in this document can be used to calculate the current sharing between conductors as well as the circulating current losses.

There is no simple rule by which the circulating current losses of parallel cables can be estimated. Calculation for each cable configuration should be applied. The principles and impedance formulae involved are straightforward but the difficulty arises in solving the large number of simultaneous equations generated. The number of equations to be solved generally precludes the use of manual calculations and solution by computer is recommended. For n_{c} cables per phase having metallic sheaths in a three-phase system there are $6 \cdot n_{\mathrm{c}}$ equations containing the same number of complex variables.

For simplicity the equations set out in this document assume that the parallel conductors all have the same cross-sectional area. If this is not the case, the equations should be adapted to allow for different resistances for each conductor. The effect of neutral and earth conductors can also be calculated by including these conductors in the appropriate loops. The method set out in this document does not take account of any portion of the sheath circulating currents that can flow through the earth or other extraneous paths. In this respect, the effect of earth return path has been excluded for the purposes of the methodology described in the following, as it is concluded that it can affect the magnitude of the resulting circulating currents only by a small extent on a limited number of cases, where both very low soil electrical resistivity values and low earthing conductor resistance values are simultaneously considered.

The conductor currents and sheath circulating currents in parallel single-core cables are unlikely to be equal. Because of this, the external thermal resistance for buried parallel cables should be calculated using the method set out in IEC 60287-2-1:2023, 4.2.3.2. Because the external thermal resistance and sheath temperatures are functions of the power dissipation from each cable in the group an iterative procedure to determine the circulating current losses and the external thermal resistance should be adopted.

ELECTRIC CABLES –
CALCULATION OF THE CURRENT RATING –

Part 1-3: Current rating equations (100 % load factor) and calculation of losses – Current sharing between parallel single-core cables and calculation of circulating current losses

1 Scope

This part of IEC 60287 provides a method for calculating the phase currents and circulating current losses in single-core cables arranged in parallel.

The method described in this document can be used for any number of cables per phase in parallel in any physical layout. The phase currents can be calculated for any arrangement of sheath bonding. For the calculation of sheath losses, it is assumed that the sheaths are bonded at both ends. A method for calculating sheath eddy current losses in two circuits in flat formation is given in IEC 60287-1-2.

2 Normative references

There are no normative references in this document.

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 https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.2 Symbols

d_c	external diameter of the conductor, mm
d_s	mean diameter of sheath or screen, mm
f	system frequency, Hz
n_c	number of cables per phase
D_mn	axial spacing between conductors, mm
$[I]$	support vector used in the calculation of current in 4.3
$I_{n\mathrm{c}}$	current in the conductor of cable n_c, A
$I_{\mathrm{s}n\mathrm{c}}$	circulating current in the sheath of cable n_c, A
$[Q]$	support matrix used in the calculation of current in 4.3
R	resistance of a conducting element, Ω/m
R_c	AC resistance of conductor at maximum operating temperature, Ω/m

R_s AC resistance of the cable sheath or screen at their maximum operating temperature, Ω/m

$X_{i,k}$ apparent mutual reactance of a pair of conductors

$[Z]$ support matrix used in the calculation of current in 4.3

ΔV conductor voltage drop, V

A coefficient depending on the construction of the conductor

λ'_{nc} sheath loss factor of cable n_c due to circulating currents

Ω angular frequency of system ($2\pi f$), s^{-1}

NOTE Subscripts m, n, i and k are used in the following only to denote rows and columns of matrices and therefore to identify specific matrix elements. They do not correspond to the respective symbols used in other parts of the IEC 60287 series for identifying physical quantities.

4 Description of method

4.1 General

The method calculates the proportion of the phase current carried by each parallel conductor and the circulating current in the sheath of each cable. The loss factor (λ') for each case is then calculated as the ratio of the losses in a sheath caused by circulating currents to the losses in the conductor of that cable.

The method of calculation set out in 4.2 and 4.3 only considers voltage drop along the conductors. Any unbalance in the load which would lead to unbalanced phase currents is ignored.

The equations to be solved for the unknown currents in the parallel conductors and their sheaths are built up from a consideration of the basic formulae for the impedance associated with a loop consisting of two long conductors lying parallel to each other and the formulae for the mutual impedance between a loop and an adjacent conductor. Consideration of these equations leads to a system of simultaneous equations for the impedance voltage for all the conductors and sheaths in a three-phase parallel cable system. The impedance voltages for all conductors in parallel in the same phase are equal. Also for the conductors representing the bonded sheaths the voltages are equal. Hence the impedance voltages can be eliminated from the equations. The sum of the currents in the parallel conductors is equal to either the known phase current or zero for the sheaths. This provides the additional information required for the solution of the simultaneous equations.

It should be noted that all the currents are complex quantities containing both real and imaginary parts.

The mutual impedance between conductors is a function of their relative positions. Hence, if the relative positions of the cables vary along the route, or the sheaths are cross-bonded, then the impedance for each section shall be calculated individually and the vector results summed in order to obtain the total impedance of each loop. If the route length is very short, then significant errors can occur in the calculated result due to the change in the relative positions of the cables as they approach the terminations.

The equations set out in this document can also be used to calculate the current sharing between cables without a metallic sheath or armour and between cables with the sheaths connected together at one end only, single-point bonded. For such calculations, the circulating current in each sheath is zero. Where cable sheaths are bonded at one end only, the standing voltage at the open circuit end of the sheath can also be determined using this method of calculation.

For the method set out in this document, it is recommended that the solution of the equations is achieved by a process of matrix algebra. This has the advantage that the solution achieved is unique and not a function of an iterative process.

4.2 Outline of method

The loss factor for the sheath in a given cable in a parallel circuit is given by:

$$\lambda'_{n_c} = \left(\frac{I_{s n_c}}{I_{n_c}} \right)^2 \frac{R_s}{R_c} \tag{1}$$

The currents I_{snc} and I_{nc} are obtained by solution of equations of the following form where there are n_c conductors in parallel and a total of $6 \cdot n_c$ conductors in a three-phase system. To simplify matters, both the phase conductors and the sheaths are referred to as conductors. The phase conductor currents are I_1, I_2, etc. The sheath currents are I_{3nc+1}, I_{3nc+2}, I_{3nc+3}, etc.

For convenience in the calculations, the following notation is used:

Cable references

Circuit	1	…	i	…	n_c
Phase R	1	…	i	…	n_c
Phase S	$n_c + 1$	…	$n_c + i$	…	$2n_c$
Phase T	$2n_c + 1$	…	$2n_c + i$	…	$3n_c$

The conductors can then be identified as follows:

Reference of a phase conductor	=	reference of the cable
Reference of a sheath conductor	=	reference of the cable + $3n_c$

For each phase the current is given by:

$$I_R [1 + j0] = \sum_{k=1}^{n_c} I_k$$

$$I_S [-0{,}5 - j0{,}866] = \sum_{k=n_c+1}^{2n_c} I_k \tag{2}$$

$$I_T [-0{,}5 + j0{,}866] = \sum_{k=2n_c+1}^{3n_c} I_k$$

The above Equations (2) assume forward phase rotation. If the phase rotation is not known, the calculation shall be carried out for both forward and reverse phase rotations.

For conductor loops representing the sheaths, the current is given by:

$$0 + j0 = \sum_{k=3n_c+1}^{6n_c} I_k \tag{3}$$

The voltage drop in each conductor is then

– for the conductors of phase R:

$$\Delta V_R = \sum_{k=1}^{6n_c} Z_{i,k} \times I_k \tag{4}$$

for i = 1 to n_c;

– for the conductors of phase S:

$$\Delta V_S = \sum_{k=1}^{6n_c} Z_{i,k} \times I_k \tag{5}$$

for i = n_c + 1 to 2 n_c;

– for the conductors of phase T:

$$\Delta V_T = \sum_{k=1}^{6n_c} Z_{i,k} \times I_k \tag{6}$$

for i = 2 n_c + 1 to 3 n_c;

– for the sheath conductors:

$$\Delta V_A = \sum_{k=1}^{6n_c} Z_{i,k} \times I_k \tag{7}$$

for i = 3 n_c + 1 to 6 n_c.

Eliminating the voltage drop from this set of equations leads to (6 n_c – 4) equations having the following form:

$$0 + j0 = \sum_{k=1}^{6n_c} zz_{i,k} \times I_k \tag{8}$$

where $zz_{i,k} = Z_{i,k} - Z_{i+1,k} = R_{i,k} + jX_{i,k}$

and R is defined as follows:

$$R = 0 \text{ if } i \neq k \qquad R = 0 \text{ if } i \neq k-1$$

For the phase conductors (refer to array [Z] in Example 1)

$$R = R_c \text{ if } i = k \text{ and } i \leq 3n_c \qquad R = -R_c \text{ if } i = k-1 \text{ and } i \leq 3n_c$$

For the sheath conductors (refer to array [Z] in Example 1)

$$R = R_s \text{ if } i = k \text{ and } i > 3n_c \qquad R = -R_s \text{ if } i = k-1 \text{ and } i > 3n_c$$

$X_{i,k}$ is regarded as a reactance and is defined as follows:

$$X_{i,k} = 2\omega 10^{-7} \ln\left(\frac{d_{i+1,k}}{d_{i,k}}\right) \tag{9}$$

where

if $i \neq k$, then $d_{i,k} = D_{m,n}$ = axial spacing between cables m and n,

with m = i if $i \leq 3n_c$ m = i – 3 n_c if $i > 3n_c$

and n = k if $k \leq 3n_c$ n = k – 3 n_c if $k > 3n_c$

If i = k and $i \leq 3n_c$ then $d_{i,k} = \alpha \dfrac{d_c}{2}$

If i = k and $i > 3n_c$ then $d_{i,k} = \dfrac{d_s}{2}$

For appropriate values of coefficient α see Table 1.

Table 1 – Values of α for conductors

Number of wires	Value of α
1 (solid)	0,779
3	0,678
7	0,726
19	0,758
37	0,768
61	0,772
91	0,774
127	0,776

The values given in Table 1 are applicable to non-compacted conductors. For compacted conductors α = 0,779 should be used. The values for hollow conductors are dependent on the inner and outer diameters of the conductor. An example of the calculation of α for hollow conductors is given in Annex B.

4.3 Matrix solution

In general the equations developed will be of the form:

$$Q = f\left(Z \times I\right)$$

where the values for Q are given by the left-hand side of Equations (2), (3) and (8). The value for Z are the coefficients of I in these equations, and the values for I are the unknown currents in the conductors and sheaths.

In matrix form the equations become:

$$\left[Q\right] = \left[Z\right] \times \left[I\right]$$

where [Z] is a square matrix of the coefficients of I_1 to I_k in Equations (2), (3) and (8).

In order to solve the unknown currents [I] the equation is written as:

$$\left[I\right] = \left[Z\right]^{-1} \times \left[Q\right]$$

where [Z]$^{-1}$ is the inverse matrix of [Z].

Example calculations using the matrix solution are given in Annex A.

Annex A
(informative)

Example calculations

A.1 Overview

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

It is assumed that the relative positions of the cables do not change over the length of the run. It is also assumed that the bonding conductors have an impedance which is negligible compared with the impedance of the conductors. The skin and proximity effects on AC resistance are ignored. The various impedance values calculated in these examples are for 1 000 m long cables.

These examples assume a supply frequency of 50 Hz.

The cable and installation parameters are as follows:

Copper conductor diameter:	32,8 mm
Conductor resistance at 20 °C:	$28,3 \cdot 10^{-6}$ Ω/m
Maximum operating temperature:	70 °C
Conductor resistance at 70 °C:	$33,86 \cdot 10^{-6}$ Ω/m
Number of wires in conductor:	127
Conductor coefficient for 127 strands:	0,776
Aluminium sheath resistance at 20 °C:	$0,18 \cdot 10^{-3}$ Ω/m
Mean diameter of sheath:	48 mm
Sheath temperature:	60 °C
Sheath resistance at 60 °C:	$0,209 \cdot 10^{-3}$ Ω/m

A.2 Example 1

A.2.1 General

The cables are laid in flat formation at 200 mm between centres with two cables per phase and no neutrals. The cable arrangement is as follows:

Cable 1	Cable 3	Cable 5	Cable 6	Cable 4	Cable 2
R1	S1	T1	T2	S2	R2

For convenience in the calculation, the conductors and sheath of each cable are numbered so that the conductors are numbered 1 to 6 and the sheaths 7 to 12. The first cable will have conductor 1 and sheath 7. The second cable being 2, 8, etc. This gives a total of 12 conductors in this example.

For a single circuit installed in flat formation at 200 mm centres, with one cable per phase, the sheath loss factors calculated in accordance with IEC 60287-1-1 are:

Table A.1 – Sheath loss factor calculation according to IEC 60287-1-1

Outer	Middle	Outer
1,99	1,50	2,62

These values are similar to the values obtained in Examples 1 and 2, but significantly different from those obtained in Example 4.

A.2.2 Calculations

The zero co-ordinates (0,0) can be fixed at any point, but it is convenient to take the axis of the lower left-hand cable as (0,0). The cable co-ordinates are entered into the array S below:

$$S = \begin{array}{c} \\ \\ \\ \\ \\ \\ \end{array}\begin{array}{cc} \boldsymbol{x} & \boldsymbol{y} \end{array}$$

$$S = \left|\begin{array}{cc} 0 & 0 \\ 1\,000 & 0 \\ 200 & 0 \\ 800 & 0 \\ 400 & 0 \\ 600 & 0 \end{array}\right| \begin{array}{l} \text{Cable 1, phase R} \\ \text{Cable 2, phase R} \\ \text{Cable 3, phase S} \\ \text{Cable 4, phase S} \\ \text{Cable 5, phase T} \\ \text{Cable 6, phase T} \end{array}$$

The axial cable spacings are calculated using the following equation:

$$m = 1 \text{ to } 6 \qquad n = 1 \text{ to } 6$$

$$D_{m,n} = \sqrt{\left(S_{m,1} - S_{n,1}\right)^2 + \left(S_{m,2} - S_{n,2}\right)^2}$$

The spacings are given in the array D below:

$$D = \left|\begin{array}{cccccc} 0 & 1\,000 & 200 & 800 & 400 & 600 \\ 1\,000 & 0 & 800 & 200 & 600 & 400 \\ 200 & 800 & 0 & 600 & 200 & 400 \\ 800 & 200 & 600 & 0 & 400 & 200 \\ 400 & 600 & 200 & 400 & 0 & 200 \\ 600 & 400 & 400 & 200 & 200 & 0 \end{array}\right|$$

Clearly this array is symmetrical about its diagonal and it is not necessary to calculate the spacing between cables m and n as well as between cables n and m.

This array is then modified to include all the values of $d_{i,k}$ required to calculate $X_{i,k}$. The modified array is given in Table A.1.

The effective reactances $X_{i,k}$ are calculated using Equation (9):

$$X_{\mathrm{i,k}} = 2\omega 10^{-7} \ln\left(\frac{d_{\mathrm{i+1,k}}}{d_{\mathrm{i,k}}}\right)$$

The coefficients, zz, for the right-hand side of Equation (8) are calculated as follows and are given in the array zz, as shown in Table A.4.

$$zz_{\mathrm{i,k}} = R_{\mathrm{i,k}} + jX_{\mathrm{i,k}}$$

where

$R = 0$	if $\mathrm{i} \neq \mathrm{k}$	$R = 0$	if $\mathrm{i} \neq \mathrm{k} - 1$
$R = R_\mathrm{c}$	if i = k and $\mathrm{i} \leq 3n_\mathrm{c}$	$R = -R_\mathrm{c}$	if i = k – 1 and $\mathrm{i} \leq 3n_\mathrm{c}$
$R = R_\mathrm{s}$	if i = k and $\mathrm{i} > 3n_\mathrm{c}$	$R = -R_\mathrm{s}$	if i = k – 1 and $\mathrm{i} > 3n_\mathrm{c}$

The coefficients for the current, I, for the right-hand side of Equations (2) and (3) are shown in array H below;

$$H = \begin{array}{|cccccccccccc|l} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Phase R} \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Phase S} \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Phase T} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & \text{Sheath} \end{array}$$

For convenience of calculation these coefficients are included in the same matrix as those obtained from consideration of the conductor loops. The new array [Z] is given in Table A.5.

The values and coefficients for the left-hand side of Equations (2) and (3) are given in array [Q] below:

$$[Q] = \begin{vmatrix} 0 \\ 1 \\ 0 \\ -0{,}5 - 0{,}866j \\ 0 \\ -0{,}5 + 0{,}866j \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The phase and sheath currents in each conductor can then be calculated by solving the simultaneous equations set out in array [Z], Table A.3, and [Q] above. These currents are given below in terms of the resistive and reactive components. Multiplying the inverse of matrix [Z] by [Q] solves the equations.

$$[I] = \begin{vmatrix} 0{,}5 \\ 0{,}5 \\ -0{,}25 - 0{,}433j \\ -0{,}25 - 0{,}433j \\ -0{,}25 + 0{,}433j \\ -0{,}25 + 0{,}433j \\ -0{,}216 - 0{,}189\,2j \\ -0{,}216 - 0{,}189\,2j \\ -0{,}130\,9 + 0{,}216\,4j \\ -0{,}130\,9 + 0{,}216\,4j \\ 0{,}346\,9 - 0{,}027\,2j \\ 0{,}346\,9 - 0{,}027\,2j \end{vmatrix}$$

The magnitude of the phase conductor and sheath currents together with the sheath loss factor are given below, assuming a total phase current of 100 A.

Phase conductor current = $\left|I_{n_\mathrm{c}}\right| \cdot 100$; Sheath current = $\left|I_{\mathrm{s}n_\mathrm{c}}\right| \cdot 100$;

$$\text{Loss factor} = \frac{\left(\left|I_{\mathrm{s}n_\mathrm{c}}\right| \cdot 100\right)^2 \cdot R_\mathrm{s}}{\left(\left|I_{n_\mathrm{c}}\right| \cdot 100\right)^2 \cdot R_\mathrm{c}}.$$

Table A.2 – Sheath current and sheath loss factor calculation per phase

	Phase current	Sheath current	Sheath loss factor
Cable 1, phase R	50	28,7	2,036
Cable 2, phase R	50	28,7	2,036
Cable 3, phase S	50	25,3	1,58
Cable 4, phase S	50	25,3	1,58
Cable 5, phase T	50	34,8	2,99
Cable 6, phase T	50	34,8	2,99

Table A.3 – Calculated values of $d_{\mathrm{i,k}}$

12,73	1 000	200	800	400	600	24	1 000	200	800	400	600
1 000	12,73	800	200	600	400	1 000	24	800	200	600	400
200	800	12,73	600	200	400	200	800	24	600	200	400
800	200	600	12,73	400	200	800	200	600	24	400	200
400	600	200	400	12,73	200	400	600	200	400	24	200
600	400	400	200	200	12,73	600	400	400	200	200	24
24	1 000	200	800	400	600	24	1 000	200	800	400	600
1 000	24	800	200	600	400	1 000	24	800	200	600	400
200	800	24	600	200	400	200	800	24	600	200	400
800	200	600	24	400	200	800	200	600	24	400	200
400	600	200	400	24	200	400	600	200	400	24	200
600	400	400	200	200	24	600	400	400	200	200	24

Table A.4 – Calculated values of zz

0,033 9 + 0,274 2j	−0,033 9−0,274 2j	0,087 1j	−0,087 1j	0,025 5j	−0,025 5j	0,234 3j	−0,234 3j	0,087 1j	−0,087 1j	0,025 5j	−0,025 5j
0,087 1j	−0,087 1j	0,033 9 + 0,242 1j	−0,0339 − 0,242 1j	0,043 6j	−0,043 6j	0,087 1j	−0,087 1j	0,202 2j	−0,202 2j	0,043 6j	−0,043 6j
0,025 5j	−0,025 5j	0,043 6j	−0,043 6j	0,033 9 + 0,173 1j	−0,033 9 − 0,173 1j	0,025 5j	−0,025 5j	0,043 6j	−0,043 6j	0,133 2j	−0,133 2j
0,234 3j	−0,234 3j	0,087 1j	−0,087 1j	0,025 5j	−0,022 5j	0,209 + 0,234 3j	−0,209 − 0,234 3j	0,087 1j	−0,087 1j	0,025 5j	−0,022 5j
−0,101 1j	0,220 3j	−0,220 3j	0,069j	−0,069j	0	−0,101 1j	0,209 + 0,220 3j	−0,209 − 0,220 3j	0,069j	−0,069j	0
0,087 1j	−0,087 1j	0,202 2j	−0,202 2j	0,043 6j	−0,043 6j	0,087 1j	−0,087 1j	0,209 + 0,202 2j	−0,209 − 0,202 2j	0,043 6j	−0,043 6j
−0,043 6j	0,069j	−0,069j	0,176 8j	−0,176 8j	0	−0,043 6j	0,069j	−0,069j	0,209 + 0,176 8j	−0,209 − 0,176 8j	0
0,025 5j	−0,025 5j	0,043 6j	−0,043 6j	0,133 2j	−0,133 2j	0,025 5j	−0,025 5j	0,043 6j	−0,0436j	0,209 + 0,133 2j	−0,209 − 0,133 2j

Table A.5 – Array [*Z*] including coefficients for currents

0,033 9 + 0,274 2*j*	−0,033 9 − 0,274 2*j*	0,087 1*j*	−0,087 1*j*	0,025 5*j*	−0,025 5*j*	0,234 3*j*	−0,234 3*j*	0,087 1*j*	−0,087 1*j*	0,025 5*j*	−0,025 5*j*
1	1	0	0	0	0	0	0	0	0	0	0
0,087 1*j*	−0,087 1*j*	0,033 9 + 0,242 1*j*	−0,033 9 − 0,242 1*j*	0,043 6*j*	−0,043 6*j*	0,087 1*j*	−0,087 1*j*	0,202 2*j*	−0,202 2*j*	0,043 6*j*	−0,043 6*j*
0	0	1	1	0	0	0	0	0	0	0	0
0,025 5*j*	−0,025 5*j*	0,043 6*j*	−0,043 6*j*	0,033 9 + 0,173 1*j*	−0,033 9 − 0,173 1*j*	0,025 5*j*	−0,025 5*j*	0,043 6*j*	−0,043 6*j*	0,133 2*j*	−0,133 2*j*
0	0	0	0	1	1	0	0	0	0	0	0
0,234 3*j*	−0,234 3*j*	0,087 1*j*	−0,087 1*j*	0,025 5*j*	−0,022 5*j*	0,209 + 0,234 3*j*	−0,209 − 0,234 3*j*	0,087 1*j*	−0,087 1*j*	0,025 5*j*	−0,022 5*j*
−0,101 1*j*	0,220 3*j*	−0,220 3*j*	0,069*j*	−0,069*j*	0	−0,101 1*j*	0,209 + 0,220 3*j*	−0,209 − 0,220 3*j*	0,069*j*	−0,069j	0
0,087 1*j*	−0,087 1*j*	0,202 2*j*	−0,202 2*j*	0,043 6*j*	−0,043 6*j*	0,087 1*j*	−0,087 1*j*	0,209 + 0,202 2*j*	−0,209 − 0,202 2*j*	0,043 6*j*	−0,043 6*j*
−0,043 6*j*	0,069*j*	−0,069*j*	0,176 8*j*	−0,176 8*j*	0	−0,043 6*j*	0,069*j*	−0,069*j*	0,209 + 0,176 8*j*	−0,209 − 0,176 8*j*	0
0,025 5*j*	−0,025 5*j*	0,043 6*j*	−0,043 6*j*	0,133 2*j*	−0,133 2*j*	0,025 5*j*	−0,025 5*j*	0,043 6*j*	−0,043 6*j*	0,209 + 0,133 2*j*	−0,209 − 0,133 2*j*
0	0	0	0	0	0	1	1	1	1	1	1

A.3 Example 2

In this example, the same cable data and spacing has been used as in Example 1, but the phase rotation has been reversed.

The magnitude of the phase conductor and sheath currents together with the sheath loss factor are given in Table A.6 below, assuming a total phase current of 100 A.

Table A.6 – Sheath current and sheath loss factor calculation per phase

	Phase current	**Sheath current**	**Sheath loss factor**
Cable 1, phase R	50	34,4	2,916
Cable 2, phase R	50	34,4	2,916
Cable 3, phase S	50	24,5	1,477
Cable 4, phase S	50	24,5	1,477
Cable 5, phase T	50	29,9	2,213
Cable 6, phase T	50	29,9	2,213

A.4 Example 3

In this example the same cable data has been used, but the six cables are now arranged in two trefoil groups with 200 mm between centres of the groups. The arrangement is shown below:

R1	R2
S1 T1	T2 S2

The cable co-ordinates are as follows:

$$D = \begin{array}{|cc|l} \boldsymbol{x} & \boldsymbol{y} & \\ 30 & 52 & \text{Cable 1, phase R} \\ 230 & 52 & \text{Cable 2, phase R} \\ 0 & 0 & \text{Cable 3, phase S} \\ 260 & 0 & \text{Cable 4, phase S} \\ 60 & 0 & \text{Cable 5, phase T} \\ 200 & 0 & \text{Cable 6, phase T} \end{array}$$

The magnitude of the phase conductor and sheath currents, together with the sheath loss factor are given in Table A.7 below, assuming a total phase current of 100 A.

Table A.7 – Sheath current and sheath loss factor calculation per phase

	Phase current	Sheath current	Sheath loss factor
Cable 1, phase R	50	13,9	0,474
Cable 2, phase R	50	13,9	0,474
Cable 3, phase S	50	13,8	0,468
Cable 4, phase S	50	13,8	0,468
Cable 5, phase T	50	14,1	0,492
Cable 6, phase T	50	14,1	0,492

A.5 Example 4

In this example, the same cable data has been used but the cables are now such that the current sharing between phase conductors is not equal. The arrangement is shown below:

R1 R2 S1 S2 T1 T2

The cable co-ordinates are as follows:

$$D = \begin{array}{cc|l} x & y & \\ \hline 0 & 0 & \text{Cable 1, phase R} \\ 400 & 0 & \text{Cable 2, phase R} \\ 800 & 0 & \text{Cable 3, phase S} \\ 1\,200 & 0 & \text{Cable 4, phase S} \\ 1\,600 & 0 & \text{Cable 5, phase T} \\ 2\,000 & 0 & \text{Cable 6, phase T} \end{array}$$

The magnitude of the phase conductor and sheath currents together with the sheath loss factor are given in Table A.8 below, assuming a total phase current of 100 A.

Table A.8 – Sheath current and sheath loss factor calculation per phase

	Phase current	Sheath current	Sheath loss factor
Cable 1, phase R	46,31	38,4	4,236
Cable 2, phase R	53,71	36,5	2,845
Cable 3, phase S	44,59	37,4	4,346
Cable 4, phase S	55,66	34,8	2,42
Cable 5, phase T	50,76	43,7	4,576
Cable 6, phase T	49,62	44,4	4,947

Comparison with Example 1 shows that the sheath losses for this cable arrangement are very high. Because of this, arrangements where all the conductors of one phase are placed together should be avoided.

Annex B
(informative)

Example of the computation of the coefficient α for hollow core conductors

Consider a hollow core conductor with internal and external diameters d_i = 17,5 mm and d_c = 33,8 mm, respectively. The following procedure can be used to calculate α.

Let $a = d_i / d_c$ = 17,5 / 33,8 = 0,518. The hollow conductor can be replaced by an equivalent conductor with the inner radius a and the outer radius equal to 1, as shown in Figure B.1.

If a fraction of the total current enclosed within the radius r is denoted by I_r then:

$$I_r = \frac{r^2 - a^2}{1 - a^2}$$

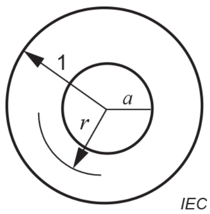

Figure B.1 – Representation of a hollow core conductor

The magnetic flux is proportional to I_r/r and the linkage flux, F, is equal to:

$$F = \int_0^1 I_r d\varphi_m = \int_0^1 \frac{\left(r^2 - a^2\right)^2}{\left(1 - a^2\right)^2} \frac{dr}{r} = \frac{0{,}25 - a^2 + a^4\left(0{,}75 - \ln a\right)}{\left(1 - a^2\right)^2}$$

$$= \frac{0{,}25 - 0{,}518^2 + 0{,}518^4\left(0{,}75 - \ln 0{,}518\right)}{\left(1 - 0{,}518^2\right)^2} = 0{,}1551$$

The coefficient α is then given by:

$$\alpha = e^{-0{,}1551} = 0{,}856$$

Bibliography

IEC 60287-1-1, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*

IEC 60287-1-2, *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*

IEC 60287-2-1:2023, *Electric cables – Calculation of the current rating – Part 2-1: Thermal resistance – Calculation of thermal resistance*

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
info@iec.ch
www.iec.ch