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Edition 2.0 2023-05
COMMENTED VERSION

INTERNATIONAL STANDARD

colour
inside

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 CMV(en)

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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

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This commented version (CMV) of the official standard IEC 60287-1-3:2023 edition 2.0 allows the user to identify the changes made to the previous IEC 60287-1-3:2002 edition 1.0. Furthermore, comments from IEC TC 20 experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

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. 1

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.

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INTRODUCTION

When single-core cables are installed in parallel, it is possible that the load current ~~may~~ 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 ~~is necessary~~ 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 ~~n~~ · n_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 ~~may~~ 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 ~~may~~ 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. 2

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 ~~it is necessary to adopt~~ 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

~~The following referenced documents are indispensable for the application 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 60287-1-2:1993, *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*~~

~~IEC 60287-2-1:1994, *Electric cables – Calculation of the current rating – Part 2: Thermal resistance – Section 1: Calculation of thermal resistance*~~

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

~~i, k elements in the series of conductors~~

~~m, n~~	~~elements in the series of cables~~
~~p~~ 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
$I_{\cancel{p}nc}$	current in the conductor of cable ~~p~~ n_c, A
$I_{s\cancel{p}nc}$	circulating current in the sheath of cable ~~p~~ 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
$\cancel{\alpha}A$	coefficient depending on the construction of the conductor
$\lambda'_{\cancel{p}nc}$	sheath loss factor of cable ~~p~~ n_c due to circulating currents
$\cancel{\omega}\Omega$	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 ~~needed~~ 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 ~~may~~ 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:

~~$\lambda'_\mathrm{p} = \left(\frac{I_\mathrm{sp}}{I_\mathrm{p}}\right)^2 \frac{R_\mathrm{s}}{R_\mathrm{c}}$ (1)~~

~~where~~

~~λ'_p is the sheath loss factor of cable p due to circulating currents;~~

~~I_sp is the circulating current in the sheath of cable p, in A;~~

~~I_p is the current in the conductor of cable p, in A;~~

~~R_s is the resistance of sheath at operating temperature, in Ω/m;~~

~~R_c is the a.c. resistance of conductor at operating temperature, in Ω/m.~~

$$\lambda'_{n_\mathrm{c}} = \left(\frac{I_{\mathrm{s}n_\mathrm{c}}}{I_{n_\mathrm{c}}}\right)^2 \frac{R_\mathrm{s}}{R_\mathrm{c}} \tag{1}$$

The currents $I_{\mathrm{s}\cancel{\mathrm{p}}n\mathrm{c}}$ and $I_{\cancel{\mathrm{p}}n\mathrm{c}}$ are obtained by solution of equations of the following form where there are $\cancel{\mathrm{p}}n_\mathrm{c}$ conductors in parallel and a total of ~~n~~ $6 \cdot n_\mathrm{c}$ 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 $I_{3\cancel{\mathrm{p}}n\mathrm{c}+1}$, $I_{3\cancel{\mathrm{p}}n\mathrm{c}+2}$, $I_{3\cancel{\mathrm{p}}n\mathrm{c}+3}$, etc.

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

Cable references

Circuit	1	…	i	…	$\cancel{\mathrm{p}}n_\mathrm{c}$
Phase R	1	…	i	…	$\cancel{\mathrm{p}}n_\mathrm{c}$
Phase S	$\cancel{\mathrm{p}}n_\mathrm{c} + 1$	…	$\cancel{\mathrm{p}}n_\mathrm{c} + \mathrm{i}$	…	$2\cancel{\mathrm{p}}n_\mathrm{c}$
Phase T	$2\cancel{\mathrm{p}}n_\mathrm{c} + 1$	…	$2\cancel{\mathrm{p}}n_\mathrm{c} + \mathrm{i}$	…	$3\cancel{\mathrm{p}}n_\mathrm{c}$

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 + 3~~p~~n_c

For each phase the current is given by:

~~$I_R[1 + j\,0] = \sum_{k=1}^{p} I_k$~~

~~$I_S[-0{,}5 - j\,0{,}866] = \sum_{k=p+1}^{2p} I_k$~~

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

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

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

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

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:

~~$0 + j\,0 = \sum_{k=3p+1}^{6p} I_k$~~

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

The voltage drop in each conductor is then

– for the conductors of phase R:

~~$\Delta V_R = \sum_{k=1}^{6p} Z_{1,k} \times I_k$~~

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

for i = 1 to ~~p~~n_c;

– for the conductors of phase S:

~~$\Delta V_S = \sum_{k=1}^{6p} Z_{i,k} \times I_k$~~

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

for i = ~~p~~n_c + 1 to 2~~p~~n_c;

– for the conductors of phase T:

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

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

for i = 2~~p~~n_c + 1 to 3~~p~~n_c;

– for the sheath conductors:

~~$\Delta V_A = \sum_{k=1}^{6p} Z_{i,k} \times I_k$~~

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

for i = 3~~p~~n_c + 1 to 6~~p~~n_c.

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

~~$0 + j0 = \sum_{k=3p+1}^{6p} zz_{i,k} \times I_k$~~

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

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

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

$R = R_c$ if i = k and i ≤ 3~~p~~n_c $\qquad$ $R = -R_c$ if i = k – 1 and i ≤ 3~~p~~n_c

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

$R = R_s$ if i = k and i > 3~~p~~n_c $\qquad$ $R = -R_s$ if i = k – 1 and i > 3~~p~~n_c

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

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

where

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

with m = i if i ≤ 3~~p~~n_c $\qquad$ m = i – 3~~p~~n_c if i > 3~~p~~n_c

and n = k if k ≤ 3~~p~~n_c $\qquad$ n = k – 3~~p~~n_c if k > 3~~p~~n_c

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

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

~~where~~

~~$\omega = 2\pi f$~~

~~f is the frequency, in Hz;~~

~~d_c is the diameter of the conductor, in mm;~~

~~d_s is the mean diameter of the sheath, in mm;~~

~~α is the coefficient depending on the construction of the conductor, see table 1.~~

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:

~~$Q_n = f(Z_n \times I_n)$~~

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

where the values for Q are given by the left-hand side of Equations (2), (3) and (8). The value for $Z_{\cancel{n}}$ are the coefficients of $I_{\cancel{n}}$ in these equations, and the values for I are the unknown currents in the conductors and sheaths.

In matrix form the equations become:

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

where $[Z]$ is a square matrix of the coefficients of I_1 to $I_{\cancel{n}k}$ in Equations (2), (3) and (8).

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

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

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

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