INTERNATIONAL STANDARD

IEC 60287-1-3

First edition
2002-05

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

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*

Reference number
IEC 60287-1-3:2002(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the 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, the IEC publishes International Standards. 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. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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International Standard IEC 60287-1-3 has been prepared by IEC technical committee 20: Electric cables.

The text of this standard is based on the following documents:

FDIS	Report on voting
20/522/FDIS	20/535/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A and B are for information only.

The committee has decided that this publication remains valid until 2008. At this date, in accordance with the committee's decision, the publication will be

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- withdrawn;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

INTRODUCTION

When single-core cables are installed in parallel the load current may 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 standard 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. 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* cables per phase having metallic sheaths in a three-phase system there are six *n* equations containing the same number of complex variables.

For simplicity the equations set out in this standard assume that the parallel conductors all have the same cross-sectional area. If this is not the case, the equations may 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 standard does not take account of any portion of the sheath circulating currents that may flow through the earth or other extraneous paths.

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 3.1 of IEC 60287-2-1. 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.

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 standard 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*

3 Symbols

d_c	diameter of the conductor, mm
d_s	mean diameter of the sheath, mm
f	frequency, Hz
i, k	elements in the series of conductors
m, n	elements in the series of cables
p	number of cables per phase
D_{mn}	axial spacing between conductors, mm
I_p	current in the conductor of cable p, A
I_{sp}	circulating current in the sheath of cable p, A
R	resistance of a conducting element, Ω/m

R_c	a.c. resistance of conductor at maximum operating temperature, Ω/m
R_s	resistance of sheath at operating temperature, Ω/m
$X_{i,k}$	apparent mutual reactance of a pair of conductors
ΔV	conductor voltage drop
α	coefficient depending on the construction of the conductor
λ'_p	sheath loss factor of cable p due to circulating currents
ω	angular frequency of system ($2\pi f$), s^{-1}

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 below 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 for 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 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 standard 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 standard, 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:

$$\lambda'_p = \left(\frac{I_{sp}}{I_p}\right)^2 \frac{R_s}{R_c} \qquad (1)$$

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.

The currents I_{sp} and I_p are obtained by solution of equations of the following form where there are p conductors in parallel and a total of n conductors. 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_{3p+1}, I_{3p+2}, I_{3p+3}, etc.

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

Cable references

Circuit	1	…	i	…	p
Phase R	1	…	i	…	p
Phase S	p + 1	…	p + i	…	2p
Phase T	2p + 1	…	2p + i	…	3p

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 + 3p

For each phase the current is given by:

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

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

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

The above equations 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:

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

The voltage drop in each conductor is then

– for the conductors of phase R:

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

for i = 1 to p;

– for the conductors of phase S:

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

for i = p + 1 to 2p;

– for the conductors of phase T:

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

for i = 2p + 1 to 3p;

– for the sheath conductors:

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

for i = 3p + 1 to 6p.

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

$$0 + j0 = \sum_{k=3p+1}^{6p} zz_{i,k} \times I_k \tag{8}$$

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

and R is defined as follows:

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