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Edition 3.0 2023-05
COMMENTED VERSION

INTERNATIONAL STANDARD

colour inside

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

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

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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.
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This commented version (CMV) of the official standard IEC 60287-1-1:2023 edition 3.0 allows the user to identify the changes made to the previous IEC 60287-1-1:2006+ AMD1:2014 edition 2.1. 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 60287-1-1 has been prepared by IEC technical committee 20: Electric cables. It is an International Standard.

This third edition cancels and replaces the second edition published in 2006 and Amendment 1:2014. This edition constitutes a technical revision.

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

a) thorough redefinition of symbols used across the IEC 60287 and IEC 60853 series to realign and unify definitions, eliminate inconsistencies and to improve cross-use of the different parts of both IEC 60287 and IEC 60853 series; 1

b) introduction of corrective factors on relevant calculated physical characteristics to take into account the effect of multicore lay-lengths; a dedicated annex to highlight correction factors for different number of cores has been introduced (Annex A).

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

Draft	Report on voting
20/2096/FDIS	20/2103/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.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 60287 contains formulae for the quantities ~~R~~ R_C, W_d, λ_1 and λ_2.

It contains methods for calculating the permissible current rating of cables from details of the permissible temperature rise, conductor resistance, losses and thermal resistivities.

Formulae for the calculation of losses are also given.

The formulae in this document contain quantities which vary with cable design and materials used. The values given in the tables are either internationally agreed, for example, electrical resistivities and resistance temperature coefficients, or are those which are generally accepted in practice, for example, thermal resistivities and permittivities of materials. In this latter category, some of the values given are not characteristic of the quality of new cables but are considered to apply to cables after a long period of use. In order that uniform and comparable results ~~may~~ can be obtained, the current ratings should be calculated with the values given in this document. However, where it is known with certainty that other values are more appropriate to the materials and design, then these may be used, and the corresponding current rating declared in addition, provided that the different values are quoted.

Quantities related to the operating conditions of cables are liable to vary considerably from one country to another. For instance, with respect to the ambient temperature and soil thermal resistivity, the values are governed in various countries by different considerations. Superficial comparisons between the values used in the various countries ~~may~~ can lead to erroneous conclusions if they are not based on common criteria: for example, there ~~may~~ can be different expectations for the life of the cables, and in some countries design is based on maximum values of soil thermal resistivity, whereas in others average values are used. Particularly, in the case of soil thermal resistivity, it is well known that this quantity is very sensitive to soil moisture content and ~~may~~ can vary significantly with time, depending on the soil type, the topographical and meteorological conditions, and the cable loading.

The following procedure for choosing the values for the various parameters should, therefore, be adopted.

Numerical values should preferably be based on results of suitable measurements. Often such results are already included in national specifications as recommended values, so that the calculation ~~may~~ can be based on these values generally used in the country in question; a survey of such values is given in IEC 60287-3-1.

A suggested list of the information required to select the appropriate type of cable is given in IEC 60287-3-1.

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General

~~1 General~~

1 Scope

This part of IEC 60287 is applicable to the conditions of steady-state operation of cables at all alternating voltages, and direct voltages up to 5 kV, buried directly in the ground, in ducts, troughs or in steel pipes, both with and without partial drying-out of the soil, as well as cables in air. The term "steady state" is intended to mean a continuous constant current (100 % load factor) just sufficient to produce asymptotically the maximum conductor temperature, the surrounding ambient conditions being assumed constant.

This document provides formulae for current ratings and losses.

The formulae given are essentially literal and designedly leave open the selection of certain important parameters. These ~~may~~ can be divided into three groups:

- parameters related to construction of a cable (for example, thermal resistivity of insulating material) for which representative values have been selected based on published work;
- parameters related to the surrounding conditions, which ~~may~~ can vary widely, the selection of which depends on the country in which the cables are used or ~~are to~~ will be used;
- parameters which result from an agreement between manufacturer and user and which involve a margin for security of service (for example, maximum conductor temperature).

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 60027-3, *Letter symbols to be used in electrical technology – Part 3: Logarithmic and related quantities, and their units*~~

~~IEC 60028:1925, *International standard of resistance for copper*~~

~~IEC 60141 (all parts), *Tests on oil-filled and gas-pressure cables and their accessories*~~

IEC 60228, *Conductors of insulated cables*

IEC 60287-1-3, *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 60287-2-1:2023, *Electric cables – Calculation of the current rating – Part 2-1: Thermal resistance – Calculation of the thermal resistance*

~~IEC 60502-1, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)*~~

~~IEC 60502-2, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV)*~~

~~IEC 60889, *Hard-drawn aluminium wire for overhead line conductors*~~

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

The symbols used in this document and the quantities which they represent are given in the following list.

~~A~~ A_A	cross-sectional area of the armour	mm^2
B_1, B_2	coefficients (see 5.4.3)	Ω/m
C	capacitance per core	F/m
C_F	coefficient defined in 5.3.6	
C_{fL}	coefficient to take into account the position of the neutral axis of the helically wound core in Annex A	
C_{gs}	coefficient used in 5.3.7.1	
C_{LL}	length correction factor for considering laying up of cores	
C_{M1}	coefficient defined in 5.3.6	
C_N	coefficient defined in 5.3.6	
C_P	coefficient defined in 5.3.4	Ω/m
C_p	coefficient used in 5.3.7.2	
C_Q	coefficient defined in 5.3.4	Ω/m
C_q	coefficient used in 5.3.7.2	
D_e^*	external diameter of cable	m
D_i	diameter over insulation	mm
D_p^*	diameter over the individual core of a multicore cable	m
D_s	external diameter of metal sheath	mm
D_{oc}	diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath	mm
D_{it}	diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath	mm

~~F~~	~~coefficient defined in 2.3.5~~	
~~H~~ E_e	intensity of solar radiation	W/m^2
H	magnetizing force (see 5.4.3)	A/m
H_s	inductance of sheath	H/m
H_1, H_2, H_3	components of inductance due to the steel wires (see 5.4.3)	H/m
I	current in one conductor (RMS value)	A
I_S	current in sheath (RMS value)	A
L_L^*	axial cable length over which the cores make one full helical turn	m
~~M, N~~	~~coefficients defined in 2.3.5~~	
~~P, Q~~	~~coefficients defined in 2.3.3~~	~~Ω/m~~
~~R~~ R_C	alternating current resistance of conductor at its maximum operating temperature per unit length of the cable	Ω/m
R_A	AC resistance of armour at its maximum operating temperature per unit length of the cable	Ω/m
R_{Ao}	AC resistance of armour at 20 °C per unit length of the cable	Ω/m
R_e	equivalent AC resistance of sheath and armour in parallel	Ω/m
R_s	AC resistance of cable sheath or screen at their maximum operating temperature per unit length of the cable	Ω/m
R_{so}	AC resistance of cable sheath or screen at 20 °C per unit length of the cable	Ω/m
R'	DC resistance of conductor at maximum operating temperature per unit length of the cable	Ω/m
R_o	DC resistance of conductor at 20 °C per unit length of the cable	Ω/m
T_1	thermal resistance per core between conductor and sheath per unit length of the cable	K · m/W
T_2	thermal resistance between sheath and armour per unit length of the cable	K · m/W
T_3	thermal resistance of external serving per unit length of the cable	K · m/W
T_4	thermal resistance of surrounding medium (ratio of cable surface temperature rise above ambient to the losses per unit length)	K · m/W
~~T_4^*~~ $T^{\#}_4$	~~external~~ thermal resistance in free air, adjusted for solar radiation	K · m/W
T_4'	thermal resistance between cable and duct (or pipe)	K · m/W
T_4''	thermal resistance of the duct (or pipe)	K · m/W
T_4'''	thermal resistance of the medium surrounding the duct (or pipe)	K · m/W
U_o	voltage between conductor and screen or sheath	V
W_A	losses in armour per unit length of the cable	W/m
W_c	losses in conductor per unit length of the cable	W/m
W_d	dielectric losses per unit length of the cable per phase	W/m

W_s	losses dissipated in sheath per unit length of the cable	W/m
$W_{(s+A)}$	total losses in sheath and armour per unit length of the cable	W/m
X	reactance of sheath (two-core cables and three-core cables in trefoil) per unit length of the cable	Ω/m
X_1	reactance of sheath (cables in flat formation)	Ω/m
X_m	mutual reactance between the sheath of one cable and the conductors of the other two when cables are in flat information	Ω/m
a	shortest minor length in a cross-bonded electrical section having unequal minor lengths	m
c	distance between the axes of conductors and the axis of the cable for three-core cables ~~(= 0,55 r_1 + 0,29 t for sector-shaped conductors)~~	mm
d	mean diameter of sheath or screen	mm
d'	mean diameter of sheath and reinforcement	mm
d_2	mean diameter of reinforcement	mm
d_A	mean diameter of armour	mm
d_c	external diameter of conductor	mm
d'_c	external diameter of equivalent round solid conductor having the same central duct as a hollow conductor	mm
d_d	internal diameter of pipe	mm
d_f	diameter of a steel wire	mm
d_i	internal diameter of hollow conductor	mm
d_M	major diameter of screen or sheath of an oval conductor	mm
d_m	minor diameter of screen or sheath of an oval conductor	mm
d_x	diameter of an equivalent circular conductor having the same cross-sectional area and degree of compactness as the shaped one	mm
f	system frequency	Hz
~~g_s~~	~~coefficient used in 2.3.6.1~~	
~~k~~ k_f	factor used in the calculation of hysteresis losses in armour or reinforcement (see 5.4.3.4)	
k_p	factor used in calculating x_p (proximity effect)	
k_s	factor used in calculating x_s (skin effect)	
~~l~~ l^*	length of a cable section (general symbol, see 5.3.5)	m
ln	natural logarithm (logarithm to base e, see IEC 60027-3)	
m	~~$\frac{\omega}{R_s} 10^{-7}$~~ parameter used in calculation of eddy-current loss factor	10^{-7} m/Ω
n	number of conductors in a cable	
n_1	number of steel wires in a cable (see 5.4.3)	
p	length of lay of a steel wire along a cable (see 5.4.3)	
~~p, q~~	~~coefficients used in 2.3.6.2~~	

r_1	circumscribing radius of two- or three-sector shaped conductors	mm
s	axial separation of conductors	mm
s_1	axial separation of two adjacent cables in a horizontal group of three, not touching	mm
s_2	~~axial separation of cables (see 2.4.2)~~	~~mm~~
	axial spacing between adjacent cables in trefoil formation; for cables in flat formation s_2 is the geometric mean of the three spacings	mm
t_0	insulation thickness between conductors	mm
t_3	thickness of the serving	mm
t_s	thickness of the sheath	mm
v	ratio of the thermal resistivities of dry and moist soils ($v = \rho_d/\rho_w$)	
x_p	argument of a Bessel function used to calculate proximity effect	
x_s	argument of a Bessel function used to calculate skin effect	
y_p	proximity effect factor (see 5.1)	
y_s	skin effect factor (see 5.1)	
α_{20}	temperature coefficient of electrical resistivity at 20 °C, per kelvin	l/K
β_1	coefficient used in 5.3.7.1	
β_2	angle between axis of armour wires and axis of cable (see 5.4.3)	
γ	angular time delay (see 5.4.3)	
Δ_1, Δ_2	coefficients used in 5.3.7.1	
δ_A	equivalent thickness of armour or reinforcement	mm
tanδ	loss factor of insulation	
ε	relative permittivity of insulation	
ε_0	permittivity of vacuum	F/m
θ	maximum operating temperature of conductor	°C
θ_a	ambient temperature	°C
θ_{ar}	maximum operating temperature of armour	°C
θ_{sc}	maximum operating temperature of cable screen or sheath	°C
θ_x	critical temperature of soil; this is the temperature of the boundary between dry and moist zones	°C
$\Delta\theta$	permissible temperature rise of conductor above ambient temperature	K
$\Delta\theta_x$	critical temperature rise of soil; this is the temperature rise of the boundary between dry and moist zones above the ambient temperature of the soil	K
λ_0	coefficient used in 5.3.7.1	
λ_1, λ_2	ratio of the total losses in metallic sheaths and armour respectively to the total conductor losses (or losses in one sheath or armour to the losses in one conductor)	

λ'_1	ratio of the losses in one sheath caused by circulating currents in the sheath to the losses in one conductor	
λ''_1	ratio of the losses in one sheath caused by eddy currents to the losses in one conductor	
λ'_{1m}	loss factor for the middle cable of three cables in flat formation without transposition, with sheaths bonded at both ends	
λ'_{11}	loss factor for the outer cable with the greater losses of three cables in flat formation without transposition, with sheaths bonded at both ends	
λ'_{12}	loss factor for the outer cable with the least losses of three cables in flat formation without transposition, with sheaths bonded at both ends	
μ	relative magnetic permeability of armour material	
μ_e	longitudinal relative permeability	
μ_t	transverse relative permeability	
ρ_{20}	conductor resistivity at 20 °C	Ω · m
ρ_d	thermal resistivity of dry soil	K · m/W
ρ_w	thermal resistivity of moist soil	K · m/W
ρ_s	sheath resistivity at 20 °C	Ω · m
σ	absorption coefficient of solar radiation for the cable surface	
ω	angular frequency of system ($2\pi f$)	

4 Permissible current rating of cables

4.1 General

When the permissible current rating is being calculated under conditions of partial drying out of the soil, it is also necessary to calculate a rating for conditions where drying out of the soil does not occur. The lower of the two ratings shall be used.

4.2 Buried cables where drying out of the soil does not occur or cables in air

4.2.1 AC cables

The permissible current rating of an AC cable can be derived from the expression for the temperature rise above ambient temperature:

~~$\Delta\theta = (I^2R + ½\, W_d)\, T_1 + [I^2R\,(1 + \lambda_1) + W_d]\, n\, T_2 + [I^2R\,(1 + \lambda_1 + \lambda_2) + W_d]\, n\,(T_3 + T_4)$~~

$$\Delta\theta = (I^2 R_C + \frac{1}{2} W_d) T_1 + n[I^2 R_C (1 + \lambda_1) + W_d] T_2 + n[I^2 R_C (1 + \lambda_1 + \lambda_2) + W_d](T_3 + T_4) \qquad (1)$$

where

I is the current flowing in one conductor (A);

$\Delta\theta$ is the conductor temperature rise above the ambient temperature (K);

NOTE The ambient temperature is the temperature of the surrounding medium under normal conditions, at a situation in which cables are installed, or will be installed, including the effect of any local source of heat, but not the increase of temperature in the immediate neighbourhood of the cables due to heat arising therefrom.

~~R~~R_C is the alternating current resistance per unit length of the ~~conductor~~ cable at maximum operating temperature (Ω/m);

W_d is the dielectric loss per unit length of the cable for the insulation surrounding the conductor (W/m);

T_1 is the thermal resistance per unit length of the cable between one conductor and the sheath (K · m/W);

T_2 is the thermal resistance per unit length of the cable of the bedding between sheath and armour (K · m/W);

T_3 is the thermal resistance per unit length of the cable of the external serving of the cable (K · m/W);

T_4 is the thermal resistance per unit length between the cable surface and the surrounding medium, as derived from IEC 60287-2-1 (K · m/W);

n is the number of load-carrying conductors in the cable (conductors of equal size and carrying the same load);

λ_1 is the ratio of losses in the metal sheath to total losses in all conductors in that cable;

λ_2 is the ratio of losses in the armouring to total losses in all conductors in that cable.

The permissible current rating is obtained from Formula (1) as follows:

~~$$I = \left[\frac{\Delta\theta - W_d \left[0{,}5\ T_1 + n\ (T_2 + T_3 + T_4)\right]}{RT_1 + nR\ (1 + \lambda_1)\ T_2\ + nR\ (1 + \lambda_1 + \lambda_2)\ (T_3 + T_4)} \right]^{0,5}$$~~

$$I = \left[\frac{\Delta\theta - W_d \left[0{,}5\ T_1 + n\ (T_2 + T_3 + T_4)\right]}{R_C T_1 + nR_C\ (1 + \lambda_1)\ T_2 + nR_C\ (1 + \lambda_1 + \lambda_2)\ (T_3 + T_4)} \right]^{0,5} \qquad (2)$$

Where the cable is exposed to direct solar radiation, the formulae given in IEC 60287-2-1:2023, 4.2.1.2 shall be used.

The current rating for a four-core low-voltage cable may be taken to be equal to the current rating of a three-core cable for the same voltage and conductor size having the same construction, provided that the cable is used in a three-phase system where the fourth conductor is either a neutral conductor or a protective conductor. When it is a neutral conductor, the current rating applies to a balanced load.

4.2.2 DC cables up to 5 kV

The permissible current rating of a DC cable is obtained from the following simplification of the AC Formula (2):

$$I = \left[\frac{\Delta\theta}{R'T_1 + nR'T_2 + nR'(T_3 + T_4)} \right]^{0,5}$$

where

R' is the direct current resistance per unit length of the ~~conductor~~ cable at maximum operating temperature (Ω/m).

Where the cable is exposed to direct solar radiation, the formulae given in IEC 60287-2-1:2023, 4.2.1.2 shall be used.