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INTERNATIONAL STANDARD

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

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CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms, definitions and symbols 8
3.1 Terms and definitions 8
3.2 Symbols 8
4 Permissible current rating of cables 12
4.1 General 12
4.2 Buried cables where drying out of the soil does not occur or cables in air 12
4.2.1 AC cables 12
4.2.2 DC cables up to 5 kV 13
4.3 Buried cables where partial drying-out of the soil occurs 13
4.3.1 AC cables 13
4.3.2 DC cables up to 5 kV 14
4.4 Buried cables where drying-out of the soil shall be avoided 14
4.4.1 AC cables 14
4.4.2 DC cables up to 5 kV 15
4.5 Cables directly exposed to solar radiation 15
4.5.1 General 15
4.5.2 AC cables 15
5 Calculation of losses 16
5.1 AC resistance of conductor 16
5.1.1 General 16
5.1.2 DC resistance of conductor 16
5.1.3 Skin effect factor y_s 16
5.1.4 Proximity effect factor y_p for two-core cables and for two single-core cables 17
5.1.5 Proximity effect factor y_p for three-core cables and for three single-core cables 17
5.1.6 Skin and proximity effects in pipe-type cables 18
5.2 Dielectric losses (applicable to AC cables only) 18
5.3 Loss factor for sheath and screen (applicable to power frequency AC cables only) 19
5.3.1 General 19
5.3.2 Two single-core cables, and three single-core cables (in trefoil formation), sheaths bonded at both ends of an electrical section 20
5.3.3 Three single-core cables in flat formation, with regular transposition, sheaths bonded at both ends of an electrical section 21
5.3.4 Three single-core cables in flat formation, without transposition, sheaths bonded at both ends of an electrical section 21
5.3.5 Variation of spacing of single-core cables between sheath bonding points 22
5.3.6 Effect of Milliken conductors 23
5.3.7 Single-core cables, with sheaths bonded at a single point or cross-bonded 23
5.3.8 Two-core unarmoured cables with common sheath 26

AVA Documents
Document Sharing Hub
Full document details: IEC 60287-1-1-2023

5.3.9 Three-core unarmoured cables with common sheath 26
5.3.10 Two-core and three-core cables with steel tape armour 27
5.3.11 Cables with each core in a separate metallic sheath (SL type) and armoured 28
5.3.12 Losses in screen and sheaths of pipe-type cables 28
5.4 Loss factor for armour, reinforcement and steel pipes (applicable to power frequency AC cables only) 29
5.4.1 General 29
5.4.2 Non-magnetic armour or reinforcement 29
5.4.3 Magnetic armour or reinforcement 30
5.4.4 Losses in steel pipes 34
Annex A (normative) Correction factor for increased lengths of individual cores within multicore cables 38
Bibliography 39

Table 1 – Electrical resistivities and temperature coefficients of metals used 35
Table 2 – Skin and proximity effects – Experimental values for the coefficients k_s and k_p 36
Table 3 – Values of relative permittivity and loss factors for the insulation of high-voltage and medium-voltage cables at power frequency 37
Table 4 – Absorption coefficient of solar radiation for cable surfaces 37
Table A.1 – Values of factor C_{fL} for different numbers of cores 38

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Full document details: IEC 60287-1-1-2023

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ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

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

FOREWORD

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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;
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).

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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.

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INTRODUCTION

This part of IEC 60287 contains formulae for the quantities 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 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 can lead to erroneous conclusions if they are not based on common criteria: for example, there 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 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 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.

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ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 1-1: Current rating equations (100 % load factor) and calculation of losses – 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 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 can vary widely, the selection of which depends on the country in which the cables are used or 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 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*

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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	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
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

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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
$T^{\#}_4$	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	mm
d	mean diameter of sheath or screen	mm
d'	mean diameter of sheath and reinforcement	mm

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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
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^*	length of a cable section (general symbol, see 5.3.5)	m
ln	natural logarithm (logarithm to base e, see IEC 60027-3)	
m	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)	
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 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)	

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α_{20}	temperature coefficient of electrical resistivity at 20 °C, per kelvin	I/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
$\tan\delta$	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

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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:

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

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_C is the alternating current resistance per unit length of the 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.

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