INTERNATIONAL STANDARD

IEC 60287-1-1

Edition 1.2
2001-11

Edition 1:1994 consolidated with amendments 1:1995 and 2:2001

Electric cables –

Calculation of the current rating –

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

*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.*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRIC CABLES –

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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 60287-1-1 has been prepared by subcommittee 20A: High-voltage cables, of IEC technical committee 20: Electric cables.

This first edition of IEC 60287-1-1 cancels and replaces sections one and two of the second edition of IEC 60287 published in 1982 and the appropriate part of amendment 3, without technical changes.

IEC 60287-2-1 replaces section three and annexes C and D of the second edition of IEC 60287; IEC 60287-3-1 replaces annexes A and B of the second edition of IEC 60287.

This consolidated version of IEC 60287-1-1 is based on the first edition (1994) [documents 20A(CO)75 and 20A(CO)81], its amendment 1 (1995) [documents 20A/262/FDIS and 20A/280/RVD] and its amendment 2 (2001) [documents 20A/477/FDIS and 20A/483/RVD].

It bears the edition number 1.2.

A vertical line in the margin shows where the base publication has been modified by amendments 1 and 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until 2006. At this date, the publication will be

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- withdrawn;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

INTRODUCTION

IEC 60287 has been divided into three parts and sections so that revisions of, and additions to, the document can be carried out more conveniently.

Each part is divided into sections which are published as separate standards.

Part 1: Formulae for ratings (100 % load factor) and power losses

Part 2: Formulae for thermal resistance

Part 3: Sections on operating conditions

Part 1 – Section 1: General, contains formulae for the quantities R, W_d, λ_1 and λ_2.

This section 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 in this section.

The formulae in this standard 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 be obtained, the current ratings should be calculated with the values given in this standard. 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 lead to erroneous conclusions if they are not based on common criteria: for example, there may 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 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 be based on these values generally used in the country in question; a survey of such values is given in part 3, section 1.

A suggested list of the information required to select the appropriate type of cable is given in part 3, section 1.

ELECTRIC CABLES –

CALCULATION OF THE CURRENT RATING –

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

1 General

1.1 Scope

This section 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 section 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 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 vary widely, the selection of which depends on the country in which the cables are used or are to 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).

1.2 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 60027, *Letter symbols to be used in electrical technology*

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

IEC 60141, *Tests on oil-filled and gas-pressure cables and their accessories*

IEC 60183:1984, *Guide to the selection of high-voltage cables*

IEC 60228:1978, *Conductors of insulated cables*
Amendment 1 (1993)

IEC 60228A:1982, *First supplement – Guide to the dimensional limits of circular conductors*

IEC 60502:1983, *Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV*

IEC 60889:1987, *Hard-drawn aluminium wire for overhead line conductors*

1.3 Symbols

The symbols used in this standard and the quantities which they represent are given in the following list:

A	cross-sectional area of the armour	mm²
B_1, B_2	coefficients (see 2.4.2)	
C	capacitance per core	F/m
D_e^*	external diameter of cable	m
D_i	diameter over insulation	mm
D_s	external diameter of metal sheath	mm
D_{oc}	the diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath	mm
D_{it}	the 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	intensity of solar radiation	W/m²
H	magnetizing force (see 2.4.2)	ampere turns/m
H_s	inductance of sheath	H/m
H_1, H_2, H_3	components of inductance due to the steel wires (see 2.4.2)	H/m
I	current in one conductor (r.m.s. value)	A
M, N	coefficients defined in 2.3.5	
P, Q	coefficients defined in 2.3.3	Ω/m
R	alternating current resistance of conductor at its maximum operating temperature	Ω/m
R_A	a.c. resistance of armour	Ω/m
R_e	equivalent a.c. resistance of sheath and armour in parallel	Ω/m
R_s	a.c. resistance of sheath	Ω/m
R'	d.c. resistance of conductor at maximum operating temperature	Ω/m
R_o	d.c. resistance of conductor at 20 °C	Ω/m
T_1	thermal resistance per core between conductor and sheath	K.m/W
T_2	thermal resistance between sheath and armour	K.m/W
T_3	thermal resistance of external serving	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^*	external thermal resistance in free air, adjusted for solar radiation	K.m/W
U_o	voltage between conductor and screen or sheath	V

W_A	losses in armour per unit length	W/m
W_c	losses in conductor per unit length	W/m
W_d	dielectric losses per unit length per phase	W/m
W_s	losses dissipated in sheath per unit length	W/m
$W_{(s+A)}$	total losses in sheath and armour per unit length	W/m
X	reactance of sheath (two-core cables and three-core cables in trefoil)	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	
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	factor used in the calculation of hysteresis losses in armour or reinforcement (see 2.4.2.4)	
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 clause 2.3 and 2.3.4)	m
ln	natural logarithm (logarithm to base e)	
m	$\frac{\omega}{R_s} 10^{-7}$	
n	number of conductors in a cable	
n_1	number of steel wires in a cable (see 2.4.2)	
p	length of lay of a steel wire along a cable (see 2.4.2)	
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
t	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 2.1)	
y_s	skin effect factor (see 2.1)	
α_{20}	temperature coefficient of electrical resistivity at 20 °C, per kelvin	l/K
β	angle between axis of armour wires and axis of cable (see 2.4.2)	
β_1	coefficient used in 2.3.6.1	
γ	angular time delay (see 2.4.2)	
Δ_1, Δ_2	coefficients used in 2.3.6.1	
δ	equivalent thickness of armour or reinforcement	mm
tan δ	loss factor of insulation	
ε	relative permittivity of insulation	
θ	maximum operating temperature of conductor	°C
θ_a	ambient temperature	°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 2.3.6.1	
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 (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 (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 (Three cables in flat formation without transposition, with sheaths bonded at both ends)	