

# INTERNATIONAL STANDARD



**Electric cables – Calculation of the current rating –  
Part 2-1: Thermal resistance – Calculation of thermal resistance**

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**Electric cables – Calculation of the current rating –  
Part 2-1: Thermal resistance – Calculation of thermal resistance**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

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# INTERNATIONAL ELECTROTECHNICAL COMMISSION

## ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

### Part 2-1: Thermal resistance – Calculation of thermal resistance

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International Standard IEC 60287-2-1 has been prepared by IEC technical committee 20: Electric cables.

This second edition of IEC 60287-2-1 cancels and replaces the first edition, published in 1994, Amendment 1:2001, Amendment 2:2006 and Corrigendum 1:2008. The document 20/1448/CDV, circulated to the National Committees as Amendment 3, led to the publication of this new edition. This edition constitutes a technical revision.

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

- a) inclusion of a reference to the use of finite element methods where analytical methods are not available for the calculation of external thermal resistance;
- b) explanation about SL and SA type cables;
- c) calculation method for T3 for unarmoured three-core cables with extruded insulation and individual copper tape screens on each core;
- d) change of condition for X in 5.4;
- e) inclusion of constants or installation conditions for water filled ducts in Table 4.

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

FDIS	Report on voting
20/1561/FDIS	20/1588/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 2.

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 publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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## 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 subdivided into ~~sections~~ **subparts** which are published as separate standards.

Part 1: Formulae of ratings and power losses

Part 2: Formulae for thermal resistance

Part 3: ~~Sections on~~ Operating conditions

This part of IEC 60287-2 contains methods for calculating the internal thermal resistance of cables and the external thermal resistance for cables laid in free air, ducts and buried.

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 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 2-1: Thermal resistance – Calculation of thermal resistance

### 1 General

#### 1 Scope

This part of IEC 60287 is solely 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, in 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 part of IEC 60287 provides formulae for thermal resistance.

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).

Equations given in this part of IEC 60287 for calculating the external thermal resistance of a cable buried directly in the ground or in a buried duct are for a limited number of installation conditions. Where analytical methods are not available for calculation of external thermal resistance finite element methods may be used. Guidance on the use of finite element methods for calculating cable current ratings is given in IEC TR 62095.

#### 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60287-1-1:2006, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*  
IEC 60287-1-1:2006/AMD1:2014

IEC 60853-2, *Calculation of the cyclic and emergency current rating of cables – Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages*

### 3 Symbols

The symbols used in this part of IEC 60287 and the quantities which they represent are given in the following list:

$D'_a$	external diameter of armour	mm
$D_d$	internal diameter of duct	mm
$D_e$	external diameter of cable, or equivalent diameter of a group of cores in pipe-type cable	mm
$D_e^*$	external diameter of cable (used in 4.2.1)	m
$D_o$	external diameter of duct	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
$D_{ot}$	the diameter of the imaginary coaxial cylinder which would just touch the outside surface of the troughs of a corrugated sheath = $D_{it} + 2t_s$	mm
$D_{ic}$	the diameter of the imaginary cylinder which would just touch the inside surface of the crests of a corrugated sheath = $D_{oc} - 2t_s$	mm
$D_{it}$	the diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath	mm
$E$	constant used in 4.2.1.1	
$F_1$	coefficient for belted cables defined in 4.1.2.2.3	
$F_2$	coefficient for belted cables defined in 4.1.2.2.6	
$G$	geometric factor for belted cables	
$\bar{G}$	geometric factor for SL and SA type cables	
$H$	intensity of solar radiation (see 4.2.1.2)	W/m <sup>2</sup>
$K$	screening factor for the thermal resistance of screened cables	
$K_A$	coefficient used in 4.2.1	
$L$	depth of laying, to cable axis or centre of trefoil	mm
$L_G$	distance from the soil surface to the centre of a duct bank	mm
$N$	number of loaded cables in a duct bank (see 4.2.7.4)	
$T_1$	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
$T'_4$	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
$U$	constant used in 4.2.7.2	
$V$	constant used in 4.2.7.2	
$W_d$	dielectric losses per unit length per phase	W/m
$W_k$	losses dissipated by cable k	W/m

$W_{TOT}$	total power dissipated in the trough per unit length	W/m
$Y$	coefficient used in 4.2.7.2	
$Z$	coefficient used in 4.2.1.1	
$d_a$	external diameter of belt insulation	mm
$d_c$	external diameter of conductor	mm
$d_{cm}$	minor diameter of an oval conductor	mm
$d_{cM}$	major diameter of an oval 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
$g$	coefficient used in 4.2.1.1	
$h$	heat dissipation coefficient	W/m <sup>2</sup> K <sup>5/4</sup>
$\ln$	natural logarithm (logarithm to base e)	
$n$	number of conductors in a cable	
$p$	the part of the perimeter of the cable trough which is effective for heat dissipation (see 4.2.6.2)	m
$r_1$	circumscribing radius of two or three-sector shaped conductors	mm
$s_1$	axial separation of two adjacent cables in a horizontal group of three, not touching	mm
$t$	insulation thickness between conductors	mm
$t_1$	insulation thickness between conductors and sheath	mm
$t_2$	thickness of the bedding	mm
$t_3$	thickness of the serving	mm
$t_i$	thickness of core insulation, including screening tapes plus half the thickness of any non-metallic tapes over the laid up cores	mm
$t_s$	thickness of the sheath	mm
$u$	$\frac{2L}{D_e}$ in 4.2.	
$u$	$\frac{L_G}{r_b}$ in 4.2.7.4	
$x, y$	sides of duct bank ( $y > x$ ) (see 4.2.7.4)	mm
$\theta_m$	mean temperature of medium between a cable and duct or pipe	°C
$\Delta\theta$	permissible temperature rise of conductor above ambient temperature	K
$\Delta\theta_d$	factor to account for dielectric loss for calculating $T_4$ for cables in free air	K
$\Delta\theta_{ds}$	factor to account for both dielectric loss and direct solar radiation for calculating $T_4^*$ for cables in free air using Figure 10	K
$\Delta\theta_{duct}$	difference between the mean temperature of air in a duct and ambient temperature	K
$\Delta\theta_s$	difference between the surface temperature of a cable in air and ambient temperature	K
$\Delta\theta_{tr}$	temperature rise of the air in a cable trough	K

$\lambda_1, \lambda_2$  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)

$\lambda'_{1m}$  loss factor for the middle cable

$\lambda'_{11}$  loss factor for the outer cable with the greater losses

$\lambda'_{12}$  loss factor for the outer cable with the least losses

Three cables in flat formation without transposition, with sheaths bonded at both ends

$\rho_i$	thermal resistivity of the insulation	K·m/W
$\rho_f$	thermal resistivity of the filler material	K·m/W
$\rho_e$	thermal resistivity of earth surrounding a duct bank	K·m/W
$\rho_c$	thermal resistivity of concrete used for a duct bank	K·m/W
$\rho_m$	thermal resistivity of metallic screens on multicore cables	K·m/W
$\rho_T$	thermal resistivity of material	K·m/W
$\sigma$	absorption coefficient of solar radiation for the cable surface	

#### 4 Calculation of thermal resistances

##### 4.1 Thermal resistance of the constituent parts of a cable, $T_1$ , $T_2$ and $T_3$

###### 4.1.1 General

Clause 4 gives the formulae for calculating the thermal resistances per unit length of the different parts of the cable  $T_1$ ,  $T_2$  and  $T_3$  (see 1.4 of ~~part 1~~ IEC 60287-1-1:2006 and IEC 60287-1-1:2006/AMD1:2014). The thermal resistivities of materials used for insulation and for protective coverings are given in Table 1.

Where screening layers are present, for thermal calculations metallic tapes are considered to be part of the conductor or sheath while semi-conducting layers (including metallized carbon paper tapes) are considered as part of the insulation. The appropriate component dimensions ~~must shall~~ be modified accordingly.

###### 4.1.2 Thermal resistance between one conductor and sheath $T_1$

###### 4.1.2.1 Single-core cables

The thermal resistance between one conductor and the sheath  $T_1$  is given by:

$$T_1 = \frac{\rho_T}{2\pi} \ln \left[ 1 + \frac{2t_1}{d_c} \right]$$

where

$\rho_T$  is the thermal resistivity of insulation (K·m/W);

$d_c$  is the diameter of conductor (mm);

$t_1$  is the thickness of insulation between conductor and sheath (mm).

NOTE For corrugated sheaths,  $t_1$  is based on the mean internal diameter of the sheath which is given by:

$$\left( \frac{D_{it} + D_{oc}}{2} \right) - t_s$$

#### 4.1.2.2 Belted cables

##### 4.1.2.2.1 General

The thermal resistance  $T_1$  between one conductor and sheath is given by:

$$T_1 = \frac{\rho_T}{2\pi} G$$

where

$G$  is the geometric factor

NOTE For corrugated sheaths,  $t_1$  is based on the mean internal diameter of the sheath which is given by:

$$\left( \frac{D_{it} + D_{oc}}{2} \right) - t_s$$

##### 4.1.2.2.2 Two-core belted cables with circular conductors

The geometric factor  $G$  is given in Figure 2.

##### 4.1.2.2.3 Two-core belted cables with sector-shaped conductors

The geometric factor  $G$  is given by:

$$G = 2 F_1 \ln \left[ \frac{d_a}{2 r_1} \right]$$

where

$$F_1 = 1 + \frac{2,2 t}{2\pi (d_x + t) - t}$$

$d_a$  is the external diameter of the belt insulation (mm);

$r_1$  is the radius of the circle circumscribing the conductors (mm);

$d_x$  is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

$t$  is the insulation thickness between conductors (mm).

##### 4.1.2.2.4 Three-core belted cables with circular conductors

For three-core belted cables with circular conductors

$$T_1 = \frac{\rho_i}{2\pi} G + 0,031(\rho_f - \rho_i) e^{0,67 \frac{t_1}{d_c}}$$

where

$\rho_i$  is the thermal resistivity of the insulation (K·m/W);

$\rho_f$  is the thermal resistivity of the filler material (K·m/W).

The geometric factor  $G$  is given in Figure 3.

NOTE For paper-insulated cables  $\rho_f = \rho_i$  and, hence, the second term on the right hand side of the above equation can be ignored.

For cables with extruded insulation, the thermal resistivity of the filler material is likely to be between 6 K·m/W and 13 K·m/W, depending on the filler material and its compaction. A value of 10 K·m/W is suggested for fibrous polypropylene fillers.

The above equation is applicable to cables with extruded insulation where each core has an individual screen of spaced wires and to cables with a common metallic screen over all three cores. For unarmoured cables of this design  $t_1$  is taken to be the thickness of the material between the conductors and outer covering (servicing).

**4.1.2.2.5 Three-core belted cables with oval conductors**

The cable shall be treated as an equivalent circular conductor cable with an equivalent diameter  $d_C = \sqrt{d_{cM} \times d_{cm}}$  (mm)

where

$d_{cM}$  is the major diameter of the oval conductor (mm);

$d_{cm}$  is the minor diameter of the oval conductor (mm).

**4.1.2.2.6 Three-core belted cables with sector-shaped conductors**

The geometric factor  $G$  for these cables depends on the shape of the sectors, which varies from one manufacturer to another. A suitable formula is:

$$G = 3F_2 \ln \left[ \frac{d_a}{2r_1} \right]$$

where

$$F_2 = 1 + \frac{3t}{2\pi(d_x + t) - t}$$

$d_a$  is the external diameter of the belt insulation (mm);

$r_1$  is the radius of the circle circumscribing the conductors (mm);

$d_x$  is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

$t$  is the insulation thickness between conductors (mm).

**4.1.2.3 Three-core cables, metal tape screened type**

**4.1.2.3.1 Screened cables with circular conductors**

~~Cables Paper insulated~~ of this type may be first considered as belted cables for which  $\frac{t_1}{t}$  is 0.5. Then, in order to take account of the thermal conductivity of the metallic screens, the result shall be multiplied by a factor  $K$ , called the screening factor, which is given in Figure 4 for different values of  $\frac{t_1}{d_C}$  and different cable specifications.

Thus:

$$T_1 = K \frac{\rho_T}{2\pi} G$$

Three-core cables with extruded insulation and individual copper tape screens on each core should be treated as SL type cables (see 4.1.2.5 and 4.1.3.2).

See 4.1.2.2.4 for three-core cables with extruded insulation and an individual screen of spaced copper wires on each core or a common metallic screen over all three cores.

**4.1.2.3.2 Screened cables with oval-shaped conductors**

The cable shall be treated as an equivalent circular conductor cable with an equivalent diameter  $d_C = \sqrt{d_{cM} \cdot d_{cm}}$ .