IEC 60287-1-1

Edition 2.0 2006-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

Câbles électriques – Calcul du courant admissible –
Partie 1-1: Equations de l'intensité du courant admissible (facteur de charge 100 %) et calcul des pertes – Généralités

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub

The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.

- IEC Just Published: www.iec.ch/online_news/justpub

Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.

- Electropedia: www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.

- Customer Service Centre: www.iec.ch/webstore/custserv

If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:
Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

A propos de la CEI

La Commission Electrotechnique Internationale (CEI) est la première organisation mondiale qui élabore et publie des normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications CEI

Le contenu technique des publications de la CEI est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

- Catalogue des publications de la CEI: www.iec.ch/searchpub/cur_fut-f.htm

Le Catalogue en-ligne de la CEI vous permet d'effectuer des recherches en utilisant différents critères (numéro de référence, texte, comité d'études,…). Il donne aussi des informations sur les projets et les publications retirées ou remplacées.

- Just Published CEI: www.iec.ch/online_news/justpub

Restez informé sur les nouvelles publications de la CEI. Just Published détaille deux fois par mois les nouvelles publications parues. Disponible en-ligne et aussi par email.

- Electropedia: www.electropedia.org

Le premier dictionnaire en ligne au monde de termes électroniques et électriques. Il contient plus de 20 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans les langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International en ligne.

- Service Clients: www.iec.ch/webstore/custserv/custserv_entry-f.htm

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions, visitez le FAQ du Service clients ou contactez-nous:
Email: csc@iec.ch
Tél.: +41 22 919 02 11
Fax: +41 22 919 03 00

IEC 60287-1-1

Edition 2.0 2006-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

Câbles électriques – Calcul du courant admissible – Partie 1-1: Equations de l'intensité du courant admissible (facteur de charge 100 %) et calcul des pertes – Généralités

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX **V**

ICS 29.060.20

ISBN 2-8318-8938-3

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

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

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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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

This second edition cancels and replaces the first edition published in 1994, Amendment 1 (1995) and Amendment 2 (2001) The document 20/780/FDIS, circulated to the National Committees as Amendment 3, led to the publication of this new edition.

The text of this standard is based on the first edition, its Amendments 1 and 2, and the following documents:

FDIS	Report on voting
20/851/FDIS	20/867/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 of 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 maintenance result date indicated on the IEC web site 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.

INTRODUCTION

This Part 1-1 contains formulae for the quantities R, 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 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 3-1.

A suggested list of the information required to select the appropriate type of cable is given in Part 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

1.1 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 part 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 60027-3, *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 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*

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 at its maximum operating temperature	Ω/m
R_{Ao}	a.c. resistance of armour at 20 °C	Ω/m
R_e	equivalent a.c. resistance of sheath and armour in parallel	Ω/m
R_s	a.c. resistance of cable sheath or screen at their maximum operating temperature	Ω/m
R_{so}	a.c. resistance of cable sheath or screen at 20 °C	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 2.3 and 2.3.4)	m
ln	natural logarithm (logarithm to base e, see IEC 60027-3)	
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	I/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_{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 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)	

μ	relative magnetic permeability of armour material	
μ_e	longitudinal relative permeability	
μ_t	transverse relative permeability	
ρ	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 ($2\pi f$)	

1.4 Permissible current rating of cables

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.

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

1.4.1.1 AC cables

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

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

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 are to 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 is the alternating current resistance per unit length of the conductor at maximum operating temperature (Ω/m);

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

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

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

T_3 is the thermal resistance per unit length 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 2.2 of Part 2 (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 the above formula as follows:

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

Where the cable is exposed to direct solar radiation, the formulae given in 2.2.1.2 of Part 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 to be 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.

1.4.1.2 DC cables up to 5 kV

The permissible current rating of a d.c. cable is obtained from the following simplification of the a.c. formula:

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

where

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

Where the cable is exposed to direct solar radiation, the formulae given in 2.2.1.2 of Part 2 shall be used.

1.4.2 Buried cables where partial drying-out of the soil occurs

1.4.2.1 AC cables

The following method shall be applied to a single isolated cable or circuit only, laid at conventional depths. The method is based on a simple two-zone approximate physical model of the soil where the zone adjacent to the cable is dried out whilst the other zone retains the site's thermal resistivity, the zone boundary being on isotherm [1]. This method is considered to be appropriate for those applications in which soil behaviour is considered in simple terms only.

NOTE Installations of more than one circuit as well as the necessary spacing between circuits are under consideration.

Changes in external thermal resistance, consequent to the formation of a dry zone around a single isolated cable or circuit, shall be obtained from the following formula (compared with the formula of 1.4.1.1):

$$I = \left[\frac{\Delta\theta - W_d \left[0{,}5\ T_1 + n\ (T_2 + T_3 + vT_4)\right] + (v - 1)\ \Delta\theta_x}{R\left[T_1 + n\ (1 + \lambda_1)\ T_2\ + n\ (1 + \lambda_1 + \lambda_2)\ (T_3 + vT_4)\right]} \right]^{0{,}5}$$

where

v is the ratio of the thermal resistivities of the dry and moist soil zones ($v = \rho_d/\rho_w$);

R is the a.c. resistance of the conductor at its maximum operating temperature (Ω/m);

[1] "Current ratings of cables buried in partially dried-out soil, Part 1": *Electra* No. 104, p. 11, January 1966 (in particular section 3 and Appendix 1).

ρ_d is the thermal resistivity of the dry soil (K.m/W);

ρ_w is the thermal resistivity of the moist soil (K.m/W);

θ_x is the critical temperature of the soil and temperature of the boundary between dry and moist zones (°C);

θ_a is the ambient temperature (°C);

$\Delta\theta_x$ is the critical temperature rise of the soil. This is the temperature rise of the boundary between the dry and moist zones above the ambient temperature of the soil ($\theta_x - \theta_a$) (K);

NOTE T_4 is calculated using the thermal resistivity of the moist soil (ρ_w) using 2.2.3.2 of Part 2. Mutual heating by modification of the temperature rise as in 2.2.3.1 of Part 2 cannot be applied.

θ_x and ρ_d shall be determined from a knowledge of the soil conditions.

NOTE The choice of suitable soil parameters is under consideration. In the meantime, values may be agreed between manufacturer and purchaser.

1.4.2.2 DC cables up to 5 kV

The permissible current rating of a d.c. cable is obtained from the following simplification of the a.c. formula:

$$I = \left[\frac{\Delta\theta + (v-1)\,\Delta\theta_x}{R'\left[T_1 + nT_2 + n\,(T_3 + vT_4)\right]} \right]^{0,5}$$

where

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

1.4.3 Buried cables where drying-out of the soil is to be avoided

1.4.3.1 AC cables

Where it is desired that moisture migration be avoided by limiting the temperature rise of the cable surface to not more than $\Delta\theta_x$, the corresponding rating shall be obtained from:

$$I = \left[\frac{\Delta\theta_x + n\,W_d\,T_4}{nRT_4\,(1 + \lambda_1 + \lambda_2)} \right]^{0,5}$$

However, depending on the value of $\Delta\theta_x$ this may result in a conductor temperature which exceeds the maximum permissible value. The current rating used shall be the lower of the two values obtained, either from the above equation or from 1.4.1.1.

The conductor resistance R shall be calculated for the appropriate conductor temperature, which may be less than the maximum permitted value. An estimate of the operating temperature shall be made and, if necessary, subsequently amended.

NOTE For four-core low-voltage cables, see the final paragraph in 1.4.1.1.

1.4.3.2 DC cables up to 5 kV

The permissible current rating of a d.c. cable shall be obtained from the following simplification of the a.c. formula:

$$I = \left[\frac{\Delta\theta_x}{nR'\, T_4} \right]^{0,5}$$

The conductor resistance R' shall be modified as in 1.4.2.2.

1.4.4 Cables directly exposed to solar radiation

Permissible current ratings

Taking into account the effect of solar radiation on a cable, the permissible current rating is given by the formulae:

1.4.4.1 AC cables

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

1.4.4.2 DC cables up to 5 kV

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

where

σ is the absorption coefficient of solar radiation for the cable surface (see Table 4);

H is the intensity of solar radiation which should be taken as 10^3 W/m² for most latitudes; it is recommended that the local value should be obtained where possible;

T_4^* is the external thermal resistance of the cable in free air, adjusted to take account of solar radiation (see part 2) (K.m/W);

D_e^* is the external diameter of cable (m) for corrugated sheaths $D_e^* = (d_{oc} + 2t_3) \cdot 10^{-3}$ (m);

t_3 is the thickness of the serving (mm).

2 Calculation of losses

2.1 AC resistance of conductor

The a.c. resistance per unit length of the conductor at its maximum operating temperature is given by the following formula, except in the case of pipe-type cables (see 2.1.5):

$$R = R'(1 + y_s + y_p)$$

where

R is the current resistance of conductor at maximum operating temperature (Ω/m);

R' is the d.c. resistance of conductor at maximum operating temperature (Ω/m);

y_s is the skin effect factor;

y_p is the proximity effect factor.