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# Overhead electrical conductors — Calculation methods for stranded bare conductors

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# National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/7, Overhead electrical conductors.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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# TECHNICAL REPORT

## Overhead electrical conductors – Calculation methods for stranded bare conductors

INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

# OVERHEAD ELECTRICAL CONDUCTORS – CALCULATION METHODS FOR STRANDED BARE CONDUCTORS

## FOREWORD

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IEC TR 61597 has been prepared by IEC technical committee 7: Overhead electrical conductors. It is a Technical Report.

This second edition cancels and replaces the first edition published in 1995. This edition constitutes a technical revision.

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

a) Addition of Clause 2 and Clause 3 since the "Normative references" and "Terms and definitions" clauses are mandatory elements of the text according to the new IEC template.
b) In Clause 6, addition of new kinds of aluminium alloy and aluminium clad steel and their values of temperature coefficients of resistance.
c) In Clause 6, addition of guidelines for the calculation of AC resistance taken into account hysteresis and eddy current losses.

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d) In Clause 7, addition of the values of coefficient of linear expansion of aluminium alloy conductor aluminium-clad steel reinforced series.

e) Deletion of Clause 8 “Calculation of maximum conductor length on drums” in the last version.

f) Annex A, replaced by “A practical example of CCC calculation”.

g) Annex B, replaced by “Indicative conditions for CCC calculation”.

The text of this Technical Report is based on the following documents:

| Draft | Report on voting |
|---|---|
| 7/704/DTR | 7/707/RVDTR |

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 Technical Report 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/standardsdev/publications.

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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# OVERHEAD ELECTRICAL CONDUCTORS – CALCULATION METHODS FOR STRANDED BARE CONDUCTORS

## 1 Scope

This document, which is a Technical Report, provides information with regard to conductors specified in IEC 61089 and other aluminium and aluminium steel conductors. Such information includes properties of conductors and useful methods of calculation. The following chapters are included in this document.

– current carrying capacity of conductors: Calculation method and typical example
– alternating current resistance, inductive and capacitive reactances
– elongation of conductors: Thermal and stress-strain data
– conductor creep
– loss of strength of aluminium wires due to high temperatures

It is noted that this document does not discuss all theories and available methods for calculating conductor properties, but provides users with simple methods that provide acceptable accuracies.

## 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 TR 60943:1998, *Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals*
IEC TR 60943:1998/AMD1:2008

IEC 61089:1991, *Round wire concentric lay overhead electrical stranded conductors*
IEC 61089:1991/AMD1:1997

IEC 60104:1987, *Aluminium-magnesium-silicon alloy wire for overhead line conductors*

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

IEC 61232:1993, *Aluminium-clad steel wires for electrical purposes*

IEC 61395:1998, *Overhead electrical conductors – Creep test procedures for stranded conductors*

IEC 62004:2007, *Thermal-resistant aluminium alloy wire for overhead line conductor*

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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- IEC Electropedia: available at http://www.electropedia.org/
  ISO Online browsing platform: available at http://www.iso.org/obp

## 4 Symbols, units and abbreviated terms

### 4.1 Symbols and units

| | |
|---|---|
| $A$ | cross-sectional area of the conductor ($mm^2$) |
| $A_a$ | cross-sectional area of aluminium wires ($mm^2$) |
| $A_s$ | cross-sectional area of steel wires ($mm^2$) |
| $D$ | conductor diameter (m) |
| $E$ | modulus of elasticity of complete conductor (MPa) |
| $E_a$ | modulus of elasticity of aluminium wires(MPa) |
| $E_s$ | modulus of elasticity of steel wires(MPa) |
| $f$ | frequency (Hz) |
| $F$ | tensile force in the complete conductor (kN) |
| $F_a$ | tensile force in the aluminium wires |
| $F_s$ | tensile force in steel wires |
| $I$ | conductor current (A) |
| $K_1$ | relative rigidity of steel to aluminium wires |
| $K_c$ | creep coefficient |
| $K_e$ | emissivity coefficient in respect to black body |
| $K_g$ | layer factor |
| $Nu$ | Nusselt number |
| $P_{conv}$ | convection heat loss (W/m) |
| $P_j$ | Joule losses (W/m) |
| $P_{rad}$ | radiation heat loss (W/m) |
| $P_{sol}$ | solar radiation heat gain (W/m) |
| $r$ | conductor radius (m) |
| $R_e$ | Reynolds number |
| $R_T$ | electrical resistance of conductor at a temperature $T$ (Ω/m) |
| $s$ | Stefan-Boltzmann constant ($5{,}67\times10^{-8}$ $W\cdot m^{-2}\cdot K^{-4}$) |
| $S_i$ | intensity of solar radiation ($W/m^2$) |
| $t$ | time (h) |
| $T$ | temperature (K) |
| $T_1$ | ambient temperature (K) |
| $T_2$ | final equilibrium temperature (K) |
| $v$ | wind speed in m/s |
| $X_c$ | capacitive reactance, calculated for 0,3 m spacing (MΩ • km) |
| $X_i$ | inductive reactance calculated for a radius of 0,3 m (Ω/km) |
| $\alpha$ | temperature coefficient of electrical resistance ($K^{-1}$) |
| $\alpha_a$ | ratio of aluminium area to total conductor area |
| $\alpha_s$ | ratio of steel area to total conductor area |
| $\beta$ | coefficient of linear expansion of conductor in $K^{-1}$ |

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$\beta_a$ coefficient of linear expansion for aluminium in $K^{-1}$

$\beta_s$ coefficient of linear expansion for steel in $K^{-1}$

$\Delta x$ general expression used to express the increment of variable $x$

$\varepsilon$ general expression of strain (unit elongation)

$\varepsilon_a$ elastic strain of aluminium wires

$\varepsilon_c$ creep and settlement strain of conductor

$\varepsilon_s$ elastic strain of steel wires

$\varepsilon_T$ thermal strain of conductor

$\Phi$ coefficient for temperature ($T$) dependence in creep calculations

$\gamma$ solar radiation absorption coefficient

$\lambda$ thermal conductivity of air film in contact with the conductor ($W \cdot m^{-1} \cdot K^{-1}$)

$\mu$ coefficient for time ($t$) dependence in creep calculations

$\sigma$ stress (MPa)

$\Psi$ coefficient for stress ($\sigma$) dependence in creep calculations

### 4.2 Abbreviated terms

CCC current carrying capacity (A)

GMR geometric mean radius of the conductor (m)

## 5 Current carrying capacity

### 5.1 General

The current carrying capacity (CCC) of a conductor is the maximum steady-state current inducing a given temperature rise in the conductor, for given ambient conditions.

The CCC depends on the type of conductor, its electrical resistance, the maximum allowable temperature rise and the ambient conditions.

### 5.2 Heat balance equation

The steady-state temperature rise of a conductor is reached whenever the heat gained by the conductor from various sources is equal to the heat losses. This is expressed by equation (1):

$$P_j + P_{\text{sol}} = P_{\text{rad}} + P_{\text{conv}} \tag{1}$$

where

$P_{\text{j}}$ is the heat generated by Joule effect

$P_{\text{sol}}$ is the solar heat gain by the conductor surface

$P_{\text{rad}}$ is the heat loss by radiation of the conductor

$P_{\text{conv}}$ is the convection heat loss

Note that magnetic heat gain (see 6.1, 6.2 and 6.3), corona heat gain, or evaporative heat loss are not taken into account in equation (1).

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### 5.3 Calculation method

In the technical literature there are many methods of calculating each component of equation (1). However, for steady-state conditions, there is reasonable agreement between the available methods and they all lead to current carrying capacities within approximately 10 % for classical conductor in operational conditions (for example, conductor temperature below 100 ℃).

NOTE Various methods were compared to IEC 60943, IEEE, practices in Germany, Japan, France, etc.

IEC TR 60943 provides a detailed and general method to compute temperature rise in electrical equipment. This method is used for calculating the current carrying capacity of conductors included in this document.

NOTE CIGRE has published a detailed method for calculating CCC in CIGRE TB 601 [4][1].

### 5.4 Joule effect

Power losses $P_j$ (W/m), due to Joule effect are given by equation (2):

$$P_j = R_T \cdot I^2 \tag{2}$$

where

$R_T$ is the electrical resistance of conductor at a temperature $T$ (Ω/m)

$I$ is the conductor current (A), AC or DC

### 5.5 Solar heat gain

Solar heat gain, $P_{sol}$ (W/m), is given by equation (3):

$$P_{sol} = \gamma \cdot D \cdot S_i \tag{3}$$

where

$\gamma$ is the solar radiation absorption coefficient

$D$ is the conductor diameter (m)

$S_i$ is the intensity of solar radiation (W/m$^2$)

### 5.6 Radiated heat loss

Heat loss by radiation, $P_{rad}$ (W/m), is given by equation (4):

$$P_{rad} = s \cdot \pi \cdot D \cdot K_e \cdot (T_2^4 - T_1^4) \tag{4}$$

where

$s$ is the Stefan-Boltzmann constant (5,67x10$^{-8}$ W·m$^{-2}$·K$^{-4}$)

$D$ is the conductor diameter (m)

$K_e$ is the emissivity coefficient in respect to black body

$T_1$ ambient temperature (K)

[1] Numbers in square brackets refer to the bibliography.

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