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Short-circuit currents – Calculation of effects –
Part 1: Definitions and calculation methods

Courants de court-circuit – Calcul des effects –
Partie 1: Définitions et méthodes de calcul

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SHORT-CIRCUIT CURRENTS – CALCULATION OF EFFECTS –

Part 1: Definitions and calculation methods

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International Standard IEC 60865-1 has been prepared by IEC technical committee 73: Short-circuit currents.

This third edition cancels and replaces the second edition published in 1993. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- The determinations for automatic reclosure together with rigid conductors have been revised.
- The influence of mid-span droppers to the span has been included.
- For vertical cable-connection the displacement and the tensile force onto the lower fixing point may now be calculated.
- Additional recommendations for foundation loads due to tensile forces have been added.

- The subclause for determination of the thermal equivalent short-circuits current has been deleted (it is now part of IEC 60909-0).
- The regulations for thermal effects of electrical equipment have been deleted.
- The standard has been reorganized and some of the symbols have been changed to follow the conceptual characteristic of international standards.

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

CDV	Report on voting
73/152/CDV	73/153/RVC

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 60865 series, under the general title, *Short-circuit currents – Calculation of effects* 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 web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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SHORT-CIRCUIT CURRENTS – CALCULATION OF EFFECTS –

Part 1: Definitions and calculation methods

1 Scope

This part of IEC 60865 is applicable to the mechanical and thermal effects of short-circuit currents. It contains procedures for the calculation of

– the electromagnetic effect on rigid conductors and flexible conductors,

– the thermal effect on bare conductors.

For cables and insulated conductors, reference is made, for example, to IEC 60949 and IEC 60986. For the electromagnetic and thermal effects in d.c. auxiliary installations of power plants and substations reference is made to IEC 61660-2.

Only a.c. systems are dealt with in this standard.

The following points should, in particular, be noted:

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a) The calculation of short-circuit currents should be based on IEC 60909. For the determination of the greatest possible short-circuit current, additional information from other IEC standards may be referred to, e.g. details about the underlying circuitry of the calculation or details about current-limiting devices, if this leads to a reduction of the mechanical stress.

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b) Short-circuit duration used in this standard depends on the protection concept and should be considered in that sense.

c) These standardized procedures are adjusted to practical requirements and contain simplifications which are conservative. Testing or more detailed methods of calculation or both may be used.

d) In Clause 5 of this standard, for arrangements with rigid conductors, only the stresses caused by short-circuit currents are calculated. Furthermore, other stresses can exist, e.g. caused by dead-load, wind, ice, operating forces or earthquakes. The combination of these loads with the short-circuit loading should be part of an agreement and/or be given by standards, e.g. erection-codes.

   The tensile forces in arrangements with flexible conductors include the effects of dead-load. With respect to the combination of other loads the considerations given above are valid.

e) The calculated loads are design loads and should be used as exceptional loads without any additional partial safety factor according to installation codes of, for example, IEC 61936-1 [1][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 60909 (all parts) *Short-circuit current calculation in three-phase a.c. systems*

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1 Figures in square brackets refer to the bibliography.

IEC 60909-0, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*

IEC 60949, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*

IEC 60986, *Short-circuit temperature limits of electric cables with rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)*

IEC 61660-2, *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 2: Calculation of effects*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document the following terms and definitions apply.

3.1.1
main conductor
conductor or arrangement composed of a number of conductors which carries the total current in one phase

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3.1.2
sub-conductor
single conductor which carries a certain part of the total current in one phase and is a part of the main conductor

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3.1.3
fixed support
support of a rigid conductor in which moments are imposed in the regarded plane

3.1.4
simple support
support of a rigid conductor in which no moments are imposed in the regarded plane

3.1.5
connecting piece
any additional mass within a span which does not belong to the uniform conductor material, includingamong others, spacers, stiffening elements, bar overlappings, branchings, etc.

3.1.6
spacer
mechanical element between sub-conductors, rigid or flexible, which, at the point of installation, maintains the clearance between sub-conductors

3.1.7
stiffening element
special spacer intended to reduce the mechanical stress of rigid conductors

3.1.8
relevant natural frequency
f_{cm}
first natural frequency of the free vibration of a single span beam without damping and natural frequency of order ν of beams with ν spans without damping

3.1.9
short-circuit tensile force
$F_{t,d}$
maximum tensile force (design value) in a flexible main conductor due to swing out reached during the short-circuit

3.1.10
drop force
$F_{f,d}$
maximum tensile force (design value) in a flexible main conductor which occurs when the span drops down after swing out

3.1.11
pinch force
$F_{pi,d}$
maximum tensile force (design value) in a bundled flexible conductor during the short-circuit due to the attraction of the sub-conductors in the bundle

3.1.12
duration of the first short-circuit current flow
T_{k1}
time interval between the initiation of the short-circuit and the first breaking of the current

3.1.13
thermal equivalent short-circuit current
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I_{th}
r.m.s. value of current having the same thermal effect and the same duration as the actual short-circuit current, which can contain d.c. component and can subside in time

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3.1.14
thermal equivalent short-circuit current density
S_{th}
ratio of the thermal equivalent short-circuit current and the cross-section area of the conductor

3.1.15
rated short-time withstand current density, S_{thr}, for conductors
r.m.s. value of the current density which a conductor is able to withstand for the rated short time

3.1.16
duration of short-circuit current
T_k
sum of the time durations of the short-circuit current flow from the initiation of the first short-circuit to the final breaking of the current in all phases

3.1.17
rated short-time
T_{kr}
time duration for which a conductor can withstand a current density equal to its rated short-time withstand current density

3.2 Symbols and units

All equations used in this standard are quantity equations in which quantity symbols represent physical quantities possessing both numerical values and dimensions.

The symbols used in this standard and the SI-units concerned are given in the following lists.

A	Cross-section of one main-conductor	m^2
A_s	Cross-section of one sub-conductor	m^2
a	Centre-line distance between conductors	m
a_m	Effective distance between main conductors	m
a_{min}	Minimum air clearance	m
a_s	Effective distance between sub-conductors	m
a_{1n}	Centre-line distance between sub-conductor 1 and sub-conductor n	m
a_{1s}	Centre-line distance between sub-conductors	m
b_h	Maximum horizontal displacement	m
b_m	Dimension of a main conductor perpendicular to the direction of the force	m
b_s	Dimension of a sub-conductor perpendicular to the direction of the force	m
C_D	Dilatation factor	1
C_F	Form factor	1
c_m	Dimension of a main conductor in the direction of the force	m
c_s	Dimension of a sub-conductor in the direction of the force	m
c_{th}	Material constant	$m^4/(A^2s)$
d	Outer diameter of a tubular or flexible conductor	m
E	Young's modulus	N/m^2
E_{eff}	Actual Young's modulus	N/m^2
e	Factor for the influence of connecting pieces	1
F	Force acting between two parallel long conductors during a short-circuit	N
F'	Characteristic electromagnetic force per unit length on flexible main conductors	N/m
F_m	Force between main conductors during a short-circuit	N
F_{m2}	Force between main conductors during a line-to-line short-circuit	N
F_{m3}	Force on the central main conductor during a balanced three-phase short-circuit	N
$F_{r,d}$	Force on support of rigid conductors (peak value, design value)	N
$F_{f,d}$	Drop force of one main conductor (design value)	N
$F_{pi,d}$	Pinch force of one main conductor (design value)	N
F_s	Force between sub-conductors during a short-circuit	N
F_{st}	Static tensile force of one flexible main conductor	N
$F_{t,d}$	Short-circuit tensile force of one main conductor (design value)	N

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F_v	Short-circuit current force between the sub-conductors in a bundle	N
f	System frequency	Hz
f_{cm}	Relevant natural frequency of a main conductor	Hz
f_{cs}	Relevant natural frequency of a sub-conductor	Hz
f_{ed}	Dynamic conductor sag at midspan	m
f_{es}	Equivalent static conductor sag at midspan	m
f_{st}	Static conductor sag at midspan	m
f_y	Stress corresponding to the yield point	N/m^2
g	Conventional value of acceleration of gravity	m/s^2
h	Height of the dropper	m
I''_k	Initial symmetrical three-phase short-circuit current (r.m.s.)	A
I''_{k1}	Initial line-to-earth short-circuit current (r.m.s.)	A
I''_{k2}	Initial symmetrical line-to-line short-circuit current (r.m.s.)	A
I_{th}	Thermal equivalent short-circuit current	A
i_p	Peak short-circuit current	A
i_{p2}	Peak short-circuit current in case of a line-to-line short-circuit	A
i_1, i_2	Instantaneous values of the currents in the conductors	A
J_m	Second moment of main conductor area	m^4
J_s	Second moment of sub-conductor area	m^4
j	Parameter determining the bundle configuration during short-circuit current flow	1
k	Number of sets of spacers or stiffening elements	1
k_{1n}	Factor for the effective distance between sub-conductor 1 and sub-conductor, n	1
k_{1s}	Factor for effective conductor distance	1
l	Centre-line distance between supports	m
l_c	Cord length of a flexible main conductor in the span	m
l_i	Length of one insulator chain	m
l_s	Centre-line distance between connecting pieces or between one connecting piece and the adjacent support	m
l_v	Cord length of a dropper	m
m'_m	Mass per unit length of main conductor	kg/m
m'_s	Mass per unit length of one sub-conductor	kg/m
m_z	Total mass of one set of connecting pieces	kg
N	Stiffness norm of an installation with flexible conductors	1/N
n	Number of sub-conductors of a main conductor	1
q	Factor of plasticity	1
r	The ratio of electromechanic force on a conductor under short-circuit conditions to gravity	1
S	Resultant spring constant of both supports of one span	N/m
S_{th}	Thermal equivalent short-circuit current density	A/mm^2

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S_{thr}	Rated short-time withstand current density	A/mm^2
T	Period of conductor oscillation	s
T_k	Duration of short-circuit current	s
T_{ki}	Duration of short-circuit i at repeating short-circuits	s
T_{kr}	Rated short-time	s
T_{k1}	Duration of the first short-circuit current flow	s
T_{res}	Resulting period of the conductor oscillation during the short-circuit current flow	s
t	Wall thickness of tubes	m
V_F	Ratio of dynamic and static force on supports	1
V_{rm}	Ratio of dynamic stress (forces on the supports, contribution of main conductor bending stress) caused by forces between main conductors with unsuccessful three-phase automatic reclosing and dynamic stress with successful three-phase automatic reclosing	1
V_{rs}	Ratio of contribution of dynamic stress caused by forces between sub-conductors with unsuccessful three-phase automatic reclosing and contribution of dynamic stress with successful three-phase automatic reclosing	1
$V_{\sigma m}$	Ratio of dynamic and static contribution of main conductor stress	1
$V_{\sigma s}$	Ratio of dynamic and static contribution of sub-conductor stress	1
W_m	Section modulus of main conductor	m^3
W_s	Section modulus of sub-conductor	m^3
w	Width of dropper	m
α	Factor for force on support	1
β	Factor for main conductor stress	1
γ	Factor for relevant natural frequency estimation	1
δ	Actual maximum swing-out angle due to the limitation of the swing-out movement by the dropper	degrees
δ_{end}	Swing-out angle at the end of the short-circuit current flow	degrees
δ_{max}	Maximum swing-out angle	degrees
δ_1	Angular direction of the force	degrees
ε_{ela}	Elastic expansion	1
ε_{pi}, ε_{st}	Strain factor of the bundle contraction	1
ε_{th}	Thermal expansion	1
ζ	Stress factor of the flexible main conductor	1
η	Factor for calculating $F_{pi,d}$ in the case of non-clashing sub-conductors	1
θ_b	Conductor temperature of the beginning of a short-circuit	°C
θ_e	Conductor temperature at the end of a short-circuit	°C
κ	Factor for the calculation of the peak short-circuit current	1
μ_0	Magnetic constant, permeability of vacuum	H/m
ν	Number of spans of a continuous beam	1

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ν_e, ν_1, ν_2, ν_3, ν_4,	Factors for calculating $F_{pi,d}$	1
ξ	Factor for calculating $F_{pi,d}$ in the case of clashing sub-conductors	1
σ_{fin}	Lowest value of cable stress when Young's modulus becomes constant	N/m^2
$\sigma_{m,d}$	Bending stress caused by the forces between main conductors (design value)	N/m^2
$\sigma_{s,d}$	Bending stress caused by the forces between sub-conductors (design value)	N/m^2
$\sigma_{tot,d}$	Total conductor stress (design value)	N/m^2
χ	Quantity for the maximum swing-out angle	1
φ, ψ	Factors for the tensile force in a flexible conductor	1

4 General

With the calculation methods presented in this standard

- stresses in rigid conductors,
- tensile forces in flexible conductors,
- forces on insulators and substructures, which might expose them to bending, tension and/or compression,
- span displacements of flexible conductors and
- heating of conductors

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can be estimated.

Electromagnetic forces are induced in conductors by the currents flowing through them. Where such electromagnetic forces interact on parallel conductors, they cause stresses that have to be taken into account at the substations. For this reason:

- the forces between parallel conductors are set forth in the following clauses;
- the electromagnetic force components set up by conductors with bends and/or cross-overs may normally be disregarded.

In the case of metal-clad systems, the change of the electromagnetic forces between the conductors due to magnetic shielding can be taken into account. In addition, however, the forces acting between each conductor and its enclosure and between the enclosures shall be considered.

When parallel conductors are long compared to the distance between them, the forces will be evenly distributed along the conductors and are given by Equation (1)

$$F = \frac{\mu_0}{2\pi} i_1 i_2 \frac{l}{a} \qquad (1)$$

where

i_1 and i_2	are the instantaneous values of the currents in the conductors;
l	is the centre-line distance between the supports;
a	is the centre-line distance between the conductors.

When the currents in the two conductors have the same direction, the forces are attractive. When the directions of the currents are opposite, the forces are repulsive.

5 Rigid conductor arrangements

5.1 General

Rigid conductors can be supported in different ways, either fixed or simple or in a combination of both. Depending on the type of support and the number of supports, the stresses in the conductors and the forces on the supports will be different for the same short-circuit current. The equations given also include the elasticity of the supports.

The stresses in the conductors and the forces on the supports also depend on the ratio between the relevant natural frequency of the mechanical system and the electrical system frequency. For example, in the case of resonance or near to resonance, the stresses and forces in the system can be amplified. If $f_{cm} / f < 0{,}5$ the response of the system decreases and the maximum stresses are in the outer phases.

5.2 Calculation of electromagnetic forces

5.2.1 Calculation of peak force between the main conductors during a three-phase short-circuit

In a three-phase system with the main conductors arranged with the same centre-line distances on the same plane, the maximum force acts on the central main conductor during a three-phase short-circuit and is given by:

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$$F_{m3} = \frac{\mu_0}{2\pi} \frac{\sqrt{3}}{2} i_p^2 \frac{l}{a_m} \quad (2)$$

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where

- i_p is the peak value of the short-circuit current in the case of a balanced three-phase short-circuit. For the calculation, see the IEC 60909 series;
- l is the maximum centre-line distance between adjacent supports;
- a_m is the effective distance between main conductors in 5.3.

NOTE Equation (2) can also be used for calculating the resulting peak force when conductors with circular cross-sections are in the corners of an equilateral triangle and where a_m is the length of the side of the triangle.

5.2.2 Calculation of peak force between the main conductors during a line-to-line short-circuit

The maximum force acting between the conductors carrying the short-circuit current during a line-to-line short-circuit in a three-phase system or in a two-line single-phase-system is given by:

$$F_{m2} = \frac{\mu_0}{2\pi} i_{p2}^2 \frac{l}{a_m} \quad (3)$$

where

- i_{p2} is the peak short-circuit current in the case of a line-to-line short-circuit;
- l is the maximum centre-line distance between adjacent supports;
- a_m is the effective distance between main conductors in 5.3.