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TECHNICAL REPORT

Short-circuit currents – Calculation of effects –
Part 2: Examples of calculation

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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.

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IEC TR 60865-2, which is a technical report, has been prepared by IEC technical committee 73: Short-circuit currents.

This second edition cancels and replaces the first edition published in 1994. This edition constitutes a technical revision.

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

a) The determinations for auto reclosure together with rigid conductors have been revised.

b) The configurations in cases of flexible conductor arrangements have been changed.

c) The influence of mid-span droppers to the span has been included.

d) For vertical cable-connection the displacement and the tensile force onto the lower fixing point may be calculated now.

e) Additional recommendations for foundation loads due to tensile forces have been added.

f) The subclause for determination of the thermal equivalent short-circuits current has been deleted (is part of IEC 60909-0:2001 now).

g) The standard IEC 60865-1:2011 has been reorganized and some of the symbols have been changed to follow the conceptual characteristic of international standards.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
73/168/DTR	73/173/RVC

Full information on the voting for the approval of this technical report 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 60865 series, published under the general title *Short-circuit currents – Calculations 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 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.

A bilingual version of this publication may be issued at a later date.

SHORT-CIRCUIT CURRENTS – CALCULATION OF EFFECTS

Part 2: Examples of calculation

1 Scope

The object of this part of IEC 60865, which is a Technical Report, is to show the application of procedures for the calculation of mechanical and thermal effects due to short circuits as presented in IEC 60865-1. Thus, this technical report is an addition to IEC 60865-1. It does not, however, change the basis for standardized procedures given in that publication.

The following points should particularly be noted:

a) The examples in this Technical Report illustrate how to make the calculations according to IEC 60865-1 in a simplified and easy-to-follow manner. They are not intended as a check for computer programs.

b) The numbers in parentheses at the end of the equations refer to the equations in IEC 60865-1:2011.

c) The system voltages are referred to as nominal voltages.

d) The results are rounded to three significant digits.

e) Short-circuit effects appear as exceptional load in addition to the mechanical loads of the normal operation of a switchgear. In the following examples with rigid conductors, a possible static preloading is therefore calculated too. Depending on whether it concerns the load of the normal operation or the load during the short-circuit different safety factors come to use. The height of these factors has been chosen typically and is recommended for the use. However, other safety factors may be necessary depending on the safety concept.

2 Normative references

IEC 60865-1:2011, *Short-Circuit Currents – Calculation of Effects – Part 1: Definitions and calculation methods*

IEC 60909-0:2001, *Short-circuit currents in three-phase AC systems – Part 0: Calculation of currents*

3 Symbols and units

For symbols and units, reference is made to IEC 60865-1:2011.

In addition, the following symbols are used:

$F_{\mathrm{str,k}}$	Dead load (characteristic value)	N
$F_{\mathrm{str,d}}$	Dead load (design value)	N
$F_{\mathrm{st,r,d}}$	Force on support of rigid conductors (design value) due to dead load	N
h_{S}, h_{I}	Height of the substructure, insulator	m
H_{s}	Horizontal component of the force at the lower fixing point of one sub-conductor of a dropper	N

$J_{st,m}$	Second moment of main conductor area with respect to the direction of the dead load	m^4
I_k	Steady-state short-circuit current (r.m.s) according to IEC 60909-0	A
l_{eff}	Effective length of a span	m
l_f	Form factor of a span	m
l_h	Extend of one head armature and clamp	m
m, n	Factor for heat effect of the d.c. component and a.c. component	1
$M_{S,d}$, $M_{I,d}$	Bending moment on the bottom on the substructure, insulator (design value)	Nm
V_s	Vertical component of the force at the upper fixing point of one sub-conductor of a dropper	N
$W_{st,m}$	Section modulus of main conductor with respect to the direction of the dead load	m^3
γ_F	Partial safety factor for action	1
γ_M	Partial safety factor for material property	1
$\sigma_{st,m,d}$	Bending stress caused by the dead load (design value)	N/m^2
$\sigma_{st,m,k}$	Bending stress caused by the dead load (characteristic value)	N/m^2

4 Example 1 – Mechanical effects on a 10 kV arrangement with single rigid conductors

4.1 General

The basis for the calculation in this example is a three-phase 10 kV busbar with one conductor per phase. The conductors are continuous beams with equidistant simple supports. The conductor arrangement is shown in Figure 1. According to IEC 61936-1 [1][1], the calculation is done for the normal load case considering the dead load of the busbar and the exceptional load case considering the combination of effects of short-circuit currents and dead load.

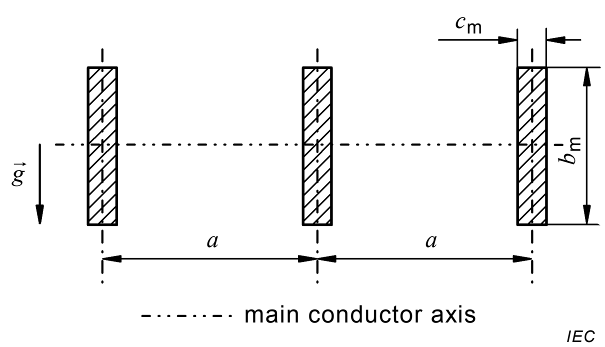

Figure 1 – Conductor arrangement

[1] The numbers in square brackets refer to the Bibliography.

4.2 Data

Initial symmetrical three-phase short-circuit current (r.m.s.)	I''_k	=	16 kA
Factor for the calculation of the peak short-circuit current	κ	=	1,35
System frequency	f	=	50 Hz
No automatic reclosing			
Number of spans		≥	3
Centre-line distance between supports	l	=	1 m
Centre-line distance between conductors	a	=	0,2 m
Rectangular conductor EN AW-6101B T7			
– Dimensions	b_m	=	60 mm
	c_m	=	10 mm
– Mass per unit length of main conductor	m'_m	=	1,62 kg/m
– Young's modulus	E	=	70 000 N/mm²
– Stress corresponding to the yield point	f_y	=	120 N/mm² to 180 N/mm²
Conventional value of acceleration of gravity	g	=	9,81 m/s²
Partial safety factors; for example according to EN 1990 [2]			
– Normal load case	γ_F	=	1,35
	γ_M	=	1,1
– Exceptional load case	$\gamma_F\ \gamma_M$	=	1,0

NOTE Safety factors differ in national standards.

4.3 Normal load case: Conductor stress and forces on the supports caused by dead load

The dead load on the conductor is:

$$F_{str,k} = m'_m\, l\, g = 1{,}62\,\frac{kg}{m} \cdot 1{,}00\ m \cdot 9{,}81\,\frac{m}{s^2} = 15{,}9\ N$$

$$F_{str,d} = \gamma_F\, F_{str,k} = 1{,}35 \cdot 15{,}9\ N = 21{,}5\ N$$

The conductor bending stress is:

$$\sigma_{st,m,k} = \frac{F_{str,k}\, l}{8\, W_{st,m}} = \frac{15{,}9\ N \cdot 1{,}00\ m}{8 \cdot 6 \cdot 10^{-6}\ m^3} = 0{,}33 \cdot 10^6\ N/m^2 = 0{,}33\ N/mm^2$$

$$\sigma_{st,m,d} = \gamma_F\, \sigma_{st,m,k} = 1{,}35 \cdot 0{,}33\ N/mm^2 = 0{,}45\ N/mm^2$$

with

$$J_{\text{st,m}} = \frac{c_\text{m} b_\text{m}^3}{12} = \frac{0{,}010 \cdot 0{,}060^3}{12}\ \text{m}^4 = 1{,}8 \cdot 10^{-7}\ \text{m}^4$$

$$W_{\text{st,m}} = \frac{J_{\text{st,m}}}{b_\text{m}/2} = \frac{1{,}8 \cdot 10^{-7}\ \text{m}^4}{0{,}03\ \text{m}} = 6 \cdot 10^{-6}\ \text{m}^3$$

NOTE The equation for the calculation of $\sigma_{\text{st,m,k}}$ gives the maximum value for two spans. The actual value for three or more spans is slightly lower.

The conductors have sufficient strength if

$$\sigma_{\text{st,m,d}} \le \frac{f_\text{y}}{\gamma_\text{M}}$$

with the lower value of f_y. The partial safety factors for normal load case γ_F, γ_M see 4.2. This gives:

$$\sigma_{\text{st,m,d}} = 0{,}45\ \text{N/mm}^2 \quad \text{less than} \quad \frac{f_\text{y}}{\gamma_\text{M}} = \frac{120\ \text{N/mm}^2}{1{,}1} = 109\ \text{N/mm}^2$$

The forces on the supports are in the direction of the dead load:

– for the outer supports (A) with $\alpha_\text{A} = 0{,}4$, see IEC 60865-1:2011, Table 3:

$$F_{\text{st,r,dA}} = \alpha_\text{A} F_{\text{str,d}} = 0{,}4 \cdot 21{,}5\ \text{N} = 8{,}6\ \text{N}$$

– for the inner supports (B) with $\alpha_\text{B} = 1{,}1$, see IEC 60865-1:2011, Table 3:

$$F_{\text{st,r,dB}} = \alpha_\text{B} F_{\text{str,d}} = 1{,}1 \cdot 21{,}5\ \text{N} = 23{,}7\ \text{N}$$

NOTE In some standards the safety factors for the supports can include the partial safety factor γ_F for action.

4.4 Exceptional load case: Effects of short-circuit currents

4.4.1 Maximum force on the central main conductor

The maximum electromagnetic force on the central main conductor is:

$$F_{\text{m3}} = \frac{\mu_0}{2\pi} \frac{\sqrt{3}}{2} i_\text{p}^2 \frac{l}{a_\text{m}} = \frac{4\pi \cdot 10^{-7}}{2\pi} \frac{\text{Vs}}{\text{Am}} \cdot \frac{\sqrt{3}}{2} \cdot \left(30{,}6 \cdot 10^3\ \text{A}\right)^2 \cdot \frac{1{,}00\ \text{m}}{0{,}202\ \text{m}} = 803\ \text{N} \qquad (2)$$

where

$$i_\text{p} = \kappa \sqrt{2}\, I_\text{k}'' = 1{,}35 \cdot \sqrt{2} \cdot 16\ \text{kA} = 30{,}6\ \text{kA} = 30{,}6 \cdot 10^3\ \text{A}$$

and the effective distance between the main conductors

$$a_\text{m} = \frac{a}{k_{12}} = \frac{0{,}20\ \text{m}}{0{,}99} = 0{,}202\ \text{m} \qquad (6)$$

with k_{12} according to IEC 60865-1:2011, Figure 1 with $a_{1\text{s}} = a$, $b_\text{s} = b_\text{m}$, $c_\text{s} = c_\text{m}$, for b_m/c_m = 60 mm/10 mm = 6, and a/c_m = 200 mm/10 mm = 20.

4.4.2 Conductor stress and forces on the supports

4.4.2.1 General

The calculations can be made according to the following 4.4.2.2 or 4.4.2.3.

4.4.2.2 Simplified method

4.4.2.2.1 Conductor bending stress

The maximum bending stress is:

$$\sigma_{\mathrm{m,d}} = V_{\sigma\mathrm{m}} V_{\mathrm{rm}} \beta \frac{F_{\mathrm{m3}} l}{8 W_{\mathrm{m}}} = 1{,}0 \cdot 0{,}73 \cdot \frac{803\ \mathrm{N} \cdot 1{,}00\ \mathrm{m}}{8 \cdot 1 \cdot 10^{-6}\ \mathrm{m}^3} = 73{,}3 \cdot 10^6\ \mathrm{N/m}^2 = 73{,}3\ \mathrm{N/mm}^2 \quad (9)$$

where

$V_{\sigma\mathrm{m}} V_{\mathrm{rm}} = 1{,}0\ (V_{\sigma\mathrm{m}} V_{\mathrm{rm}})_{\max}$	according to IEC 60865-1:2011, Table 2
$\beta = 0{,}73$	according to IEC 60865-1:2011, Table 3

$$W_{\mathrm{m}} = \frac{J_{\mathrm{m}}}{c_{\mathrm{m}}/2} = \frac{0{,}5 \cdot 10^{-8}\ \mathrm{m}^4}{0{,}005\ \mathrm{m}} = 1 \cdot 10^{-6}\mathrm{m}^3$$

The busbar is assumed to withstand the short-circuit force if

$$\sigma_{\mathrm{m,d}} + \sigma_{\mathrm{st,m,k}} \le q\, f_{\mathrm{y}} \quad (11)$$

with the lower value of f_{y}. $\sigma_{\mathrm{st,m,k}}$ see 4.3. For rectangular cross-section $q = 1{,}5$, see IEC 60865-1:2011, Table 4. This gives:

$$\sigma_{\mathrm{m,d}} + \sigma_{\mathrm{st,m,k}} = 73{,}3\ \mathrm{N/mm}^2 + 0{,}33\ \mathrm{N/mm}^2 = 73{,}6\ \mathrm{N/mm}^2 \quad \text{less than} \quad q\, f_{\mathrm{y}} = 1{,}5 \cdot 120\ \mathrm{N/mm}^2 = 180\ \mathrm{N/mm}^2$$

4.4.2.2.2 Forces on the supports

The equivalent static force on the supports is:

$$F_{\mathrm{r,d}} = V_{\mathrm{F}} V_{\mathrm{rm}}\, \alpha\, F_{\mathrm{m3}} \quad (15)$$

According to IEC 60865-1:2011, Table 2, with the upper value of f_{y} and $\sigma_{\mathrm{tot,d}} = \sigma_{\mathrm{m,d}} + \sigma_{\mathrm{st,m,k}}$ it is:

$$\frac{\sigma_{\mathrm{tot,d}}}{0{,}8\, f_{\mathrm{y}}} = \frac{73{,}6\ \mathrm{N/mm}^2}{0{,}8 \cdot 180\ \mathrm{N/mm}^2} = 0{,}511$$

Therefore, with a three-phase short-circuit we meet range 2 in IEC 60865-1:2011, Table 2,

$$0{,}370 < \frac{\sigma_{\mathrm{tot,d}}}{0{,}8\, f_{\mathrm{y}}} < 1$$

hence

$$V_F V_{rm} = \frac{0{,}8 f_y}{\sigma_{tot,d}} = \frac{1}{0{,}511} = 1{,}96$$

For the outer supports (A) it is with α_A = 0,4, see IEC 60865-1:2011, Table 3:

$$F_{r,dA} = V_F V_{rm} \alpha_A F_{m3} = 1{,}96 \cdot 0{,}4 \cdot 803 \text{ N} = 630 \text{ N}$$

For the inner supports (B) it is with α_B = 1,1, see IEC 60865-1:2011, Table 3:

$$F_{r,dB} = V_F V_{rm} \alpha_B F_{m3} = 1{,}96 \cdot 1{,}1 \cdot 803 \text{ N} = 1731 \text{ N}$$

4.4.2.3 Detailed method

4.4.2.3.1 Relevant natural frequency f_{cm} and factors V_F, V_{rm} and $V_{\sigma m}$

The relevant natural frequency of the main conductor is:

$$f_{cm} = \frac{\gamma}{l^2}\sqrt{\frac{E J_m}{m'_m}} = \frac{3{,}56}{(1{,}00 \text{ m})^2} \cdot \sqrt{\frac{7 \cdot 10^{10} \text{ N/m}^2 \cdot 0{,}5 \cdot 10^{-8} \text{ m}^4}{1{,}62 \text{ kg/m}}} = 52{,}3 \text{ Hz} \qquad (16)$$

where

γ = 3,56 according to IEC 60865-1:2011, Table 3

J_m = 0,5 · 10^{-8}m^4 see 4.4.2.2.1

The frequency ratio is:

$$\frac{f_{cm}}{f} = \frac{52{,}3 \text{ Hz}}{50 \text{ Hz}} = 1{,}05$$

From Figure 4 and 5.7.3 of IEC 60865-1:2011, the following values for the factors V_F, $V_{\sigma m}$ and V_{rm} are obtained:

$$V_F = 1{,}8$$
$$V_{\sigma m} = 1{,}0$$
$$V_{rm} = 1{,}0$$

4.4.2.3.2 Conductor bending stress

The maximum bending stress is:

$$\sigma_{m,d} = V_{\sigma m} V_{rm} \beta \frac{F_{m3}\, l}{8 W_m} = 1{,}0 \cdot 1{,}0 \cdot 0{,}73 \cdot \frac{803 \text{ N} \cdot 1{,}00 \text{ m}}{8 \cdot 1 \cdot 10^{-6} \text{ m}^3} = 73{,}3 \cdot 10^6 \text{ N/m}^2 = 73{,}3 \text{ N/mm}^2 \qquad (9)$$

where

$V_{\sigma m} V_{rm}$ = 1,0·1,0 according to 4.4.2.3.1

β = 0,73 according to IEC 60865-1:2011, Table 3

W_m = 1·10^{-6}m^3 see 4.4.2.2.1

The busbar is assumed to withstand the short-circuit force if

$$\sigma_{\text{m,d}} + \sigma_{\text{st,m,k}} \le q\, f_{\text{y}} \tag{11}$$

with the lower value of f_{y}. $\sigma_{\text{st,m,k}}$ see 4.3. For rectangular cross-section q = 1,5, see IEC 60865-1:2011, Table 4. This gives:

$$\sigma_{\text{m,d}} + \sigma_{\text{st,m,k}} = 73{,}3\ \text{N/mm}^2 + 0{,}33\ \text{N/mm}^2 = 73{,}6\ \text{N/mm}^2 \quad \text{less than} \quad q\, f_{\text{y}} = 1{,}5 \cdot 120\ \text{N/mm}^2 = 180\ \text{N/mm}^2$$

4.4.2.3.3 Forces on the supports

The equivalent static force on supports becomes:

$$F_{\text{r,d}} = V_{\text{F}}\, V_{\text{rm}}\, \alpha\, F_{\text{m3}} \tag{15}$$

According to IEC 60865-1:2011, Table 2, with the upper value of f_{y} and $\sigma_{\text{tot,d}} = \sigma_{\text{m,d}} + \sigma_{\text{st,m,k}}$ it is:

$$\frac{\sigma_{\text{tot,d}}}{0{,}8\, f_{\text{y}}} = \frac{73{,}6\ \text{N/mm}^2}{0{,}8 \cdot 180\ \text{N/mm}^2} = 0{,}511$$

Therefore, with a three-phase short-circuit we meet range 2 in IEC 60865-1:2011, Table 2,

$$0{,}370 < \frac{\sigma_{\text{tot,d}}}{0{,}8\, f_{\text{y}}} < 1$$

hence

$$V_{\text{F}}\, V_{\text{rm}} = \frac{0{,}8\, f_{\text{y}}}{\sigma_{\text{tot,d}}} = \frac{1}{0{,}511} = 1{,}96$$

According to 4.4.2.3.1 above, $V_{\text{F}}\, V_{\text{rm}} = 1{,}8 \cdot 1{,}0 = 1{,}8$ which is less than the value 1,96 according to IEC 60865-1:2011, Table 2.

For the outer supports (A) it is with α_{A} = 0,4, see IEC 60865-1:2011, Table 3:

$$F_{\text{r,dA}} = V_{\text{F}}\, V_{\text{rm}}\, \alpha_{\text{A}}\, F_{\text{m3}} = 1{,}8 \cdot 1{,}0 \cdot 0{,}4 \cdot 803\ \text{N} = 578\ \text{N}$$

For the inner supports (B) it is with α_{B} = 1,1, see IEC 60865-1:2011, Table 3:

$$F_{\text{r,dB}} = V_{\text{F}}\, V_{\text{rm}}\, \alpha_{\text{B}}\, F_{\text{m3}} = 1{,}8 \cdot 1{,}0 \cdot 1{,}1 \cdot 803\ \text{N} = 1590\ \text{N}$$

4.5 Conclusions

The busbar will withstand the dead load

The calculated bending stress is	$\sigma_{\text{st,m,d}}$	1 N/mm^2
The outer supports have to withstand a vertical force of	$F_{\text{st,r,dA}}$	9 N
The inner supports have to withstand a vertical force of	$F_{\text{st,r,dB}}$	24 N