

# **Short-circuit currents — Calculation of effects**

## **Part 2. Examples of calculation**

# Committees responsible for this Published Document

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## National foreword

This Published Document has been prepared under the direction of the Electrotechnical Sector Board. It is identical with IEC 865-2 : 1994 *Short-circuit currents — Calculation of effects, Part 2: Examples of calculation*, published by the International Electrotechnical Commission (IEC). The IEC document has been published as a type 2 Technical Report hence is entirely informative in nature and does not change the basis for the standardized procedures given in BS EN 60865-1.

### Cross-reference

| International standard | Corresponding British Standard                                                                                                 |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| IEC 865-1 : 1993       | BS EN 60865 <i>Short-circuit currents — Calculation of effects</i><br>Part 1 : 1994 <i>Definitions and calculation methods</i> |

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

## SHORT-CIRCUIT CURRENTS – CALCULATION OF EFFECTS

### Part 2: Examples of calculation

#### 1 Scope and object

The object of this IEC 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 865-1. Thus, this technical report is an addition to IEC 865-1. It does not, however, change the basis for standardized procedures given in that publication.

##### NOTES

- 1 The examples in this Technical Report illustrate how to make the calculations according to IEC 865-1 in a simplified and easy-to-follow manner. They are not intended as a check for computer programs.
- 2 The numbers in parentheses at the end of the equations refer to the equations in IEC 865-1.
- 3 The system voltages are referred to as nominal voltages.

#### 2 Reference document

IEC 865-1: 1993, *Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods*

#### 3 Symbols and units

For symbols and units, reference is made to IEC 865-1.

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

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.

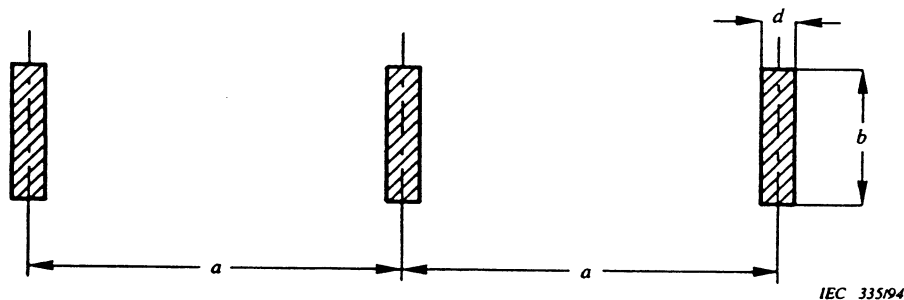


Figure 1 – Conductor arrangement

##### 4.1 Data

|                                                                |                            |
|----------------------------------------------------------------|----------------------------|
| Three-phase initial symmetrical short-circuit current (r.m.s.) | $I''_{k3} = 16 \text{ kA}$ |
|----------------------------------------------------------------|----------------------------|

|                                                      |                 |
|------------------------------------------------------|-----------------|
| Factor for calculation of peak short-circuit current | $\kappa = 1,35$ |
|------------------------------------------------------|-----------------|

|                        |                     |
|------------------------|---------------------|
| System frequency       | $f = 50 \text{ Hz}$ |
| No automatic reclosing |                     |

|                 |          |
|-----------------|----------|
| Number of spans | $\geq 3$ |
|-----------------|----------|

|                           |                   |
|---------------------------|-------------------|
| Distance between supports | $l = 1 \text{ m}$ |
|---------------------------|-------------------|

|                                         |                     |
|-----------------------------------------|---------------------|
| Centre-line distance between conductors | $a = 0,2 \text{ m}$ |
|-----------------------------------------|---------------------|

Rectangular conductor of AlMgSi0,5

- |                                           |                                                                   |
|-------------------------------------------|-------------------------------------------------------------------|
| – Dimensions                              | $b = 60 \text{ mm}$<br>$d = 10 \text{ mm}$                        |
| – Mass per unit length                    | $m' = 1,62 \text{ kg/m}$                                          |
| – Young's modulus                         | $E = 70\,000 \text{ N/mm}^2$                                      |
| – Stress corresponding to the yield point | $R_{p0,2} = 120 \text{ N/mm}^2 \text{ up to } 180 \text{ N/mm}^2$ |

#### 4.2 Maximum force on the central main conductor

$$F_{m3} = \frac{\mu_0}{2\pi} \frac{\sqrt{3}}{2} i_{p3}^2 \frac{l}{a_m} = \frac{4\pi \cdot 10^{-7}}{2\pi} \frac{V_s}{A_m} \times \frac{\sqrt{3}}{2} \times (30,6 \cdot 10^3 \text{ A})^2 \times \frac{1,00 \text{ m}}{0,202 \text{ m}} = 803 \text{ N} \quad (2)$$

where

$$i_{p3} = \sqrt{2} \kappa I''_{k3} = \sqrt{2} \times 1,35 \times 16 \text{ kA} = 30,6 \text{ kA} = 30,6 \cdot 10^3 \text{ A}$$

and the effective distance between the main conductors

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

with  $k_{12}$  according to IEC 865-1 figure 1 for  $b/d = 6$ ,  $a_{1s} = a$  and  $a/d = 20$ .

#### 4.3 Conductor stress and forces on supports

Calculation can be made according to the following 4.3.1 or 4.3.2.

##### 4.3.1 Simplified method

##### 4.3.1.1 Conductor bending stress

$$\begin{aligned} \sigma_{\text{tot}} = \sigma_m &= V_\sigma V_r \beta \frac{F_{m3} l}{8Z} \\ &= 1,0 \times 0,73 \times \frac{803 \text{ N} \times 1,00 \text{ m}}{8 \times 1 \cdot 10^{-6} \text{ m}^3} = 73,3 \cdot 10^6 \text{ N/m}^2 = 73,3 \text{ N/mm}^2 \end{aligned} \quad (9,12)$$

where

$$V_\sigma V_r = 1,0 = (V_\sigma V_r)_{\text{max}}$$

according to IEC 865-1, table 2

$$\beta = 0,73$$

according to IEC 865-1, table 3

$$J = \frac{bd^3}{12} = \frac{0,06 \times 0,010^3}{12} \text{ m}^4 = 0,5 \cdot 10^{-8} \text{ m}^4$$

$$Z = \frac{J}{d/2} = \frac{0,5 \cdot 10^{-8} \text{ m}^4}{0,005 \text{ m}} = 1 \cdot 10^{-6} \text{ m}^3$$

The busbars are assumed to withstand the short-circuit force if

$$\sigma_{\text{tot}} \leq q R_{p0,2} \quad (13)$$

With the lower value of  $R_{p0,2}$ . For a rectangular cross-section  $q = 1,5$ , see IEC 865-1, table 4. This gives:

$$\sigma_{\text{tot}} = 73,3 \text{ N/mm}^2 \text{ less than } 1,5 \times 120 \text{ N/mm}^2 = 180 \text{ N/mm}^2$$

##### 4.3.1.2 Bending force on the supports

$$F_d = V_F V_r \propto F_{m3} \quad (15)$$

According to IEC 865-1, table 2 with the upper value of  $R_{p0,2}$  it is:

$$\frac{\sigma_{\text{tot}}}{0,8 \cdot R_{p0,2}} = \frac{73,3 \text{ N/mm}^2}{0,8 \times 180 \text{ N/mm}^2} = 0,509$$

therefore, with a three-phase short circuit

$$0,370 < \frac{\sigma_{\text{tot}}}{0,8 \cdot R_{p0,2}} < 1$$

Hence

$$V_F V_r = \frac{0,8 \cdot R_{p0,2}}{\sigma_{\text{tot}}} = \frac{0,8 \times 180 \text{ N/mm}^2}{73,3 \text{ N/mm}^2} = 1,97$$

For the outer supports (A) is with  $\alpha_A = 0,4$ , see IEC 865-1, table 3:

$$F_{dA} = V_F V_r \alpha_A F_{m3} = 1,97 \times 0,4 \times 803 \text{ N} = 633 \text{ N}$$

For the inner supports (B) is with  $\alpha_B = 1,1$ , see IEC 865-1, table 3:

$$F_{dB} = V_F V_r \alpha_B F_{m3} = 1,97 \times 1,1 \times 803 \text{ N} = 1\,740 \text{ N}$$

#### 4.3.2 Detailed method

##### 4.3.2.1 Natural frequency $f_c$ and factors $V_F$ , $V_r$ and $V_\sigma$

$$f_c = \frac{\gamma}{l^2} \sqrt{\frac{EJ}{m'}} = \frac{3,56}{(1,00 \text{ m})^2} \sqrt{\frac{7 \cdot 10^{10} \text{ N/m}^2 \times 0,5 \cdot 10^{-8} \text{ m}^4}{1,62 \text{ kg/m}}} = 52,3 \text{ Hz} \quad (16)$$

where

$\gamma = 3,56$  according to IEC 865-1, table 3

$J = 0,5 \cdot 10^{-8} \text{ m}^4$  (see 4.3.1.1).

The ratio  $f_c/f$  is 1,05. From IEC 865-1, figure 4 and 2.2.2.6.2 the following values for the factors  $V_F$ ,  $V_\sigma$  and  $V_r$  are obtained:

$$V_F = 1,8$$

$$V_\sigma = 1,0$$

$$V_r = 1,0$$

##### 4.3.2.2 Conductor bending stress

The conductor bending stress is:

$$\sigma_{\text{tot}} = \sigma_m = V_\sigma V_r \beta \frac{F_{m3} l}{8Z} \quad (9,12)$$

$$= 1,0 \times 1,0 \times 0,73 \frac{803 \text{ N} \times 1,00 \text{ m}}{8 \times 1 \cdot 10^{-6} \text{ m}^3} = 73,3 \cdot 10^6 \text{ N/m}^2 = 73,3 \text{ N/mm}^2$$

where

$$V_{\sigma} V_r = 1,0 \times 1,0$$

according to 4.3.2.1 above

$$\beta = 0,73$$

according to IEC 865-1, table 3

$$Z = 1 \cdot 10^{-6} \text{ m}^3$$

(see 4.3.1.1).

The busbars are assumed to withstand the short-circuit force if

$$\sigma_{\text{tot}} \leq q R_{p0,2} \quad (13)$$

with the lower value of  $R_{p0,2}$ . For a rectangular cross-section  $q = 1,5$ , see IEC 865-1, table 4. This gives:

$$\sigma_{\text{tot}} = 73,3 \text{ N/mm}^2 \text{ less than } 1,5 \times 120 \text{ N/mm}^2 = 180 \text{ N/mm}^2$$

#### 4.3.2.3 Bending force on the supports

$$F_d = V_F V_r \alpha F_{m3} \quad (15)$$

According to 4.3.2.1 above,  $V_F V_r = 1,8 \times 1,0 = 1,8$  which is lower than the value 1,97 from IEC 865-1 table 2, see 4.3.1.2.

For the outer supports (A) is with  $\alpha_A = 0,4$ , see IEC 865-1, table 3:

$$F_{dA} = V_F V_r \alpha_A F_{m3} = 1,8 \times 1,0 \times 0,4 \times 803 \text{ N} = 578 \text{ N}$$

For the inner supports (B) is with  $\alpha_B = 1,1$ , see IEC 865-1, table 3:

$$F_{dB} = V_F V_r \alpha_B F_{m3} = 1,8 \times 1,0 \times 1,1 \times 803 \text{ N} = 1\,590 \text{ N}$$

#### 4.3.3 Conclusions

The busbars will withstand the short-circuit force.

|                                                                 |                   | <i>Simplified<br/>method</i> | <i>Detailed<br/>method</i> |
|-----------------------------------------------------------------|-------------------|------------------------------|----------------------------|
| The calculated bending stresses $\sigma_{\text{tot}}$ are:      | N/mm <sup>2</sup> | 73,3                         | 73,3                       |
| The outer supports have to withstand a dynamic bending force of | N                 | 633                          | 578                        |
| The inner supports have to withstand a dynamic bending force of | N                 | 1 740                        | 1 590                      |

## 5 Example 2 – Mechanical effects on a 10 kV arrangement with multiple rigid conductors

The basis for the calculation in this example is the same three-phase 10 kV busbar as in example 1, but now with three sub-conductors per main conductor as shown in figure 2. The cross-sections of the sub-conductors are 60 mm × 10 mm as the conductors of example 1.

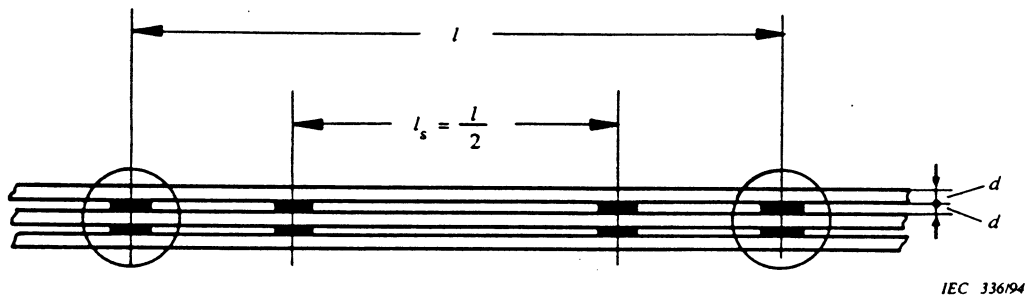


Figure 2 – Position of the spacers and sub-conductors

### 5.1 Data (additional to the data of example 1)

|                                                          |                                                           |
|----------------------------------------------------------|-----------------------------------------------------------|
| Number of sub-conductors                                 | $n = 3$                                                   |
| Dimension of sub-conductor in the direction of the force | $d = 10 \text{ mm}$                                       |
| Number of spacers                                        | $k = 2$                                                   |
| Distance between spacers                                 | $l_s = 0,5 \text{ m}$                                     |
| Dimension of spacers of AlMgSi0,5                        | $60 \text{ mm} \times 60 \text{ mm} \times 10 \text{ mm}$ |

### 5.2 Maximum force on the central main conductor

$$F_{m3} = \frac{\mu_0}{2\pi} \frac{\sqrt{3}}{2} i_{p3}^2 \frac{l}{a_m} = \frac{4\pi \cdot 10^{-7}}{2\pi} \frac{\text{Vs}}{\text{Am}} \times \frac{\sqrt{3}}{2} \times (30,6 \cdot 10^3 \text{ A})^2 \times \frac{1,00 \text{ m}}{0,20 \text{ m}} = 811 \text{ N} \quad (2)$$

where

$$i_{p3} = \sqrt{2} \kappa I'_{k3} = \sqrt{2} \times 1,35 \times 16 \text{ kA} = 30,6 \text{ kA} = 30,6 \cdot 10^3 \text{ A}$$

and the effective distance between the main conductors

$$a_m = \frac{a}{k_{12}} = \frac{0,2}{1,00} = 0,20 \text{ m} \quad (6)$$

with  $k_{12}$  according to IEC 865-1 figure 1 for  $b_m/d_m = 60 \text{ mm}/50 \text{ mm} = 1,2$  and  $a/d_m = 200 \text{ mm}/50 \text{ mm} = 4$ . The dimensions  $b_m$  and  $d_m$  are shown in IEC 865-1, figure 2b.

### 5.3 Maximum force on the outer sub-conductor between two adjacent connecting pieces

$$F_s = \frac{\mu_0}{2\pi} \left( \frac{i_{p3}}{n} \right)^2 \frac{l_s}{a_s} = \frac{4\pi \cdot 10^{-7}}{2\pi} \frac{V_s}{\text{Am}} \times \left( \frac{30,6 \cdot 10^3 \text{ A}}{3} \right)^2 \times \frac{0,5 \text{ m}}{20,2 \cdot 10^{-3} \text{ m}} = 515 \text{ N} \quad (4)$$

where

$$\frac{1}{a_s} = \frac{k_{12}}{a_{12}} + \frac{k_{13}}{a_{13}} = \frac{0,60}{20 \text{ mm}} + \frac{0,78}{40 \text{ mm}} = \frac{1}{20,2 \text{ mm}} \quad (8)$$

with  $k_{12}$  and  $k_{13}$  from IEC 865, figure 1:

- $k_{12} = 0,60$  for  $a_{12}/d = 20 \text{ mm}/10 \text{ mm} = 2$  and  $b/d = 6$
  - $k_{13} = 0,78$  for  $a_{13}/d = 40 \text{ mm}/10 \text{ mm} = 4$  and  $b/d = 6$
- or  $a_s$  from IEC 865-1, table 1.

### 5.4 Conductor stress and forces on support

Calculations can be made according to the following 5.4.1 or according to the following 5.4.2.

#### 5.4.1 Simplified method

##### 5.4.1.1 Bending stress caused by the forces between main conductors

$$\begin{aligned} \sigma_m &= V_\sigma V_r \beta \frac{F_{m3} l}{8Z} \\ &= 1,0 \times 0,73 \times \frac{811 \text{ N} \times 1,00 \text{ m}}{8 \times 3 \cdot 10^{-6} \text{ m}^3} = 24,7 \cdot 10^6 \text{ N/m}^2 = 24,7 \text{ N/mm}^2 \end{aligned} \quad (9)$$

where

$$\begin{aligned} V_\sigma V_r &= 1,0 = (V_\sigma V_r)_{\max} && \text{according to IEC 865-1, table 2} \\ \beta &= 0,73 && \text{according to IEC 865-1, table 3} \end{aligned}$$

$$Z = n \frac{bd^2}{6} = 3 \times \frac{0,06 \times 0,01^2}{6} \text{ m}^3 = 3 \cdot 10^{-6} \text{ m}^3 \quad \text{according to IEC 865-1, 2.2.2.3}$$

##### 5.4.1.2 Bending stress caused by the forces between the sub-conductors

$$\begin{aligned} \sigma_s &= V_{\sigma s} V_r \frac{F_s l_s}{16Z_s} \\ &= 1,0 \times \frac{515 \text{ N} \times 0,5 \text{ m}}{16 \times 1 \cdot 10^{-6} \text{ m}^3} = 16,1 \cdot 10^6 \text{ N/m}^2 = 16,1 \text{ N/mm}^2 \end{aligned} \quad (10)$$

where

$$\begin{aligned} V_{\sigma s} V_r &= 1,0 = (V_{\sigma s} V_r)_{\max} && \text{according to IEC 865-1, table 2} \\ Z_s &= 1 \cdot 10^{-6} \text{ m}^3 && \text{as } Z \text{ in 4.3.1.1 (example 1).} \end{aligned}$$

#### 5.4.1.3 Total bending stress in the busbar material

$$\sigma_{\text{tot}} = \sigma_m + \sigma_s = 24,7 \text{ N/mm}^2 + 16,1 \text{ N/mm}^2 = 40,8 \text{ N/mm}^2 \quad (12)$$

The busbars are assumed to withstand the short-circuit force if

$$\sigma_{\text{tot}} \leq q R_{p0,2} \quad (13)$$

$$\sigma_s \leq R_{p0,2} \quad (14)$$

with the lower value of  $R_{p0,2}$ . For a rectangular cross-section  $q = 1,5$ , see IEC 865-1, table 4 or 2.2.2.3. This gives:

$$\sigma_{\text{tot}} = 40,8 \text{ N/mm}^2 \text{ less than } 1,5 \times 120 \text{ N/mm}^2 = 180 \text{ N/mm}^2$$

$$\sigma_s = 16,1 \text{ N/mm}^2 \text{ less than } 120 \text{ N/mm}^2$$

#### 5.4.1.4 Bending force on supports

$$F_d = V_F V_r \propto F_{m3} \quad (15)$$

According to IEC 865-1 table 2, with the upper value of  $R_{p0,2}$  it is:

$$\frac{\sigma_{\text{tot}}}{0,8 \cdot R_{p0,2}} = \frac{40,8 \text{ N/mm}^2}{0,8 \times 180 \text{ N/mm}^2} = 0,283$$

therefore with a three-phase short circuit

$$\frac{\sigma_{\text{tot}}}{0,8 \cdot R_{p0,2}} \leq 0,370$$

Hence

$$V_F V_r = 2,7$$

For the outer supports (A) is with  $\alpha_A = 0,4$ , see IEC 865-1, table 3:

$$F_{dA} = 2,7 \times 0,4 \times 811 \text{ N} = 876 \text{ N}$$

For the inner supports (B) is with  $\alpha_B = 1,1$ , see IEC 865-1, table 3:

$$F_{dB} = 2,7 \times 1,1 \times 811 \text{ N} = 2\,409 \text{ N}$$

#### 5.4.2 Detailed method

##### 5.4.2.1 Natural frequency $f_c$ of the main conductor, $f_{cs}$ of the sub-conductors and factors $V_F$ , $V_\sigma$ , $V_{\sigma s}$ , $V_r$ and $V_{rs}$

$$f_c = c \frac{\gamma}{l^2} \sqrt{\frac{EJ_s}{m'_s}} = 0,97 \times \frac{3,56}{(1,00 \text{ m})^2} \times \sqrt{\frac{7 \cdot 10^{10} \text{ N/m}^2 \times 0,5 \cdot 10^{-8} \text{ m}^4}{1,62 \text{ kg/m}}} = 50,8 \text{ Hz} \quad (17)$$

where

$$c = 0,97$$

according to IEC 865-1, figure 3c for  $k = 2$  and the ratio

$$\frac{m_z}{n m'_s l} = \frac{1,62 \text{ kg/m} \times 0,06 \text{ m} \times 2}{3 \times 1,62 \text{ kg/m} \times 1,00 \text{ m}} = 0,04$$

$$\gamma = 3,56 \quad \text{from IEC 865-1, table 3}$$

$$J = 0,5 \cdot 10^{-8} \text{ m}^4 \quad \text{as } J \text{ in example 1.}$$

$$f_{cs} = \frac{3,56}{l_s^2} \sqrt{\frac{E J_s}{m'_s}} = \frac{3,56}{(0,5 \text{ m})^2} \times \sqrt{\frac{7 \cdot 10^{10} \text{ N/m}^2 \times 0,5 \cdot 10^{-8} \text{ m}^4}{1,62 \text{ kg/m}}} = 209 \text{ Hz} \quad (18)$$

The ratio  $f_c/f$  is 1,02 and  $f_{cs}/f$  is 4,18. This gives from IEC 865-1, figure 4 and 2.2.2.6.2 the following values to the factors  $V_F$ ,  $V_\sigma$ ,  $V_{\sigma s}$ ,  $V_r$  and  $V_{rs}$ :

$$V_F = 1,8$$

$$V_\sigma = 1,0$$

$$V_{\sigma s} = 1,0$$

$$V_r = 1,0$$

$$V_{rs} = 1,0$$

#### 5.4.2.2 Bending stress caused by the forces between main conductors

$$\begin{aligned} \sigma_m &= V_\sigma V_r \beta \frac{F_{m3} l}{8Z} \\ &= 1,0 \times 1,0 \times 0,73 \times \frac{811 \text{ N} \times 1,00 \text{ m}}{8 \times 3 \cdot 10^{-6} \text{ m}^3} = 24,7 \cdot 10^6 \text{ N/m}^2 = 24,7 \text{ N/mm}^2 \end{aligned} \quad (9)$$

where

$$V_\sigma V_r = 1,0 \times 1,0$$

according to 5.4.2.1 above

$$\beta = 0,73$$

according to IEC 865-1, table 3

$$Z = n \frac{bd^2}{6} = 3 \times \frac{0,06 \times 0,01^2}{6} \text{ m}^3 = 3 \cdot 10^{-6} \text{ m}^3 \quad \text{according to IEC 865-1, 2.2.2.3}$$

#### 5.4.2.3 Bending stress caused by the forces between the sub-conductors

$$\begin{aligned} \sigma_s &= V_{\sigma s} V_{rs} \frac{F_s l_s}{16Z_s} \\ &= 1,0 \times 1,0 \times \frac{515 \text{ N} \times 0,5 \text{ m}}{16 \times 1 \cdot 10^{-6} \text{ m}^3} = 16,1 \cdot 10^6 \text{ N/m}^2 = 16,1 \text{ N/mm}^2 \end{aligned} \quad (10)$$

where

$$V_{\sigma s} V_{rs} = 1,0 \times 1,0$$

according to 865-1, table 2

$$Z_s = 1 \cdot 10^{-6} \text{ m}^3$$

as  $Z$  in 4.3.1.1 (example 1)

#### 5.4.2.4 Total bending stress in the busbar material

$$\sigma_{\text{tot}} = \sigma_m + \sigma_s = 24,7 \text{ N/mm}^2 + 16,1 \text{ N/mm}^2 = 40,8 \text{ N/mm}^2 \quad (12)$$

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

$$\sigma_{\text{tot}} \leq q R_{p0,2} \quad (13)$$

$$\sigma_s \leq R_{p0,2} \quad (14)$$

with the lower value of  $R_{p0,2}$ . For a rectangular cross-section  $q = 1,5$ , see IEC 865-1, table 4. This gives:

$$\begin{aligned} \sigma_{\text{tot}} &= 40,8 \text{ N/mm}^2 \text{ less than } 1,5 \times 120 \text{ N/mm}^2 = 180 \text{ N/mm}^2 \\ \sigma_s &= 16,1 \text{ N/mm}^2 \text{ less than } 120 \text{ N/mm}^2 \end{aligned}$$

#### 5.4.2.5 Bending force on the supports

$$F_d = V_F V_r \alpha F_{m3} \quad (15)$$

According to 5.4.2.1 above,  $V_F V_r = 1,8 \times 1,0 = 1,8$  which is lower than the value 2,7 obtained from IEC 865-1, table 2 in the case of the simplified method, see 5.4.1.4.

For the outer supports (A) is with  $\alpha_A = 0,4$ , see IEC 865-1, table 3:

$$F_{dA} = V_F V_r \alpha_A F_{m3} = 1,8 \times 1,0 \times 0,4 \times 811 \text{ N} = 584 \text{ N}$$

For the inner supports (B) is with  $\alpha_B = 1,1$ , see IEC 865-1, table 3:

$$F_{dB} = V_F V_r \alpha_B F_{m3} = 1,8 \times 1,0 \times 1,1 \times 811 \text{ N} = 1\,606 \text{ N}$$

#### 5.4.3 Conclusions

|                                                                 |                       |                   | Simplified<br>method | Detailed<br>method |
|-----------------------------------------------------------------|-----------------------|-------------------|----------------------|--------------------|
| The busbars will withstand the short-circuit force.             |                       |                   |                      |                    |
| The calculated bending stresses are                             | $\sigma_{\text{tot}}$ | N/mm <sup>2</sup> | 40,8                 | 40,8               |
|                                                                 | $\sigma_s$            | N/mm <sup>2</sup> | 16,1                 | 16,1               |
| The outer supports have to withstand a dynamic bending force of |                       |                   |                      |                    |
|                                                                 |                       | N                 | 876                  | 584                |
| The inner supports have to withstand a dynamic bending force of |                       |                   |                      |                    |
|                                                                 |                       | N                 | 2 409                | 1 606              |