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BSI Standards Publication

Determination of cross-sectional area of conductors and selection of protective devices

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National foreword

This Published Document is the UK implementation of CLC/TR 50480:2012.

The requirements for electrical installations are given in BS 7671:2008. This Technical Report sets out a uniform approach to the calculations required for the determination of cross-sectional area of conductors and the selection of the appropriate protective devices to meet the requirements of BS 7671. The main body of the technical report was developed by CENELEC TC 64. National Annex NA provides details of additional and alternative calculation methods that are used in the UK.

The UK participation in its preparation was entrusted to Technical Committee JPEL/64, Electrical installations of buildings — Joint committee.

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

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English version

Determination of cross-sectional area of conductors and selection of protective devices

Détermination des sections des conducteurs et choix des dispositifs de protection

Festlegung von Leiterquerschnitten und Auswahl von Schutzeinrichtungen

This Technical Report was approved by CENELEC on 2011-01-02.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC
European Committee for Electrotechnical Standardization
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Foreword

This Technical Report was prepared by CENELEC Technical Committee 64, Electrical installations and protection against electric shock.

The text of the draft was circulated for voting in accordance with the Internal Regulations, Part 2, Subclause 11.4.3.3 (simple majority) and was approved by CENELEC as CLC/TR 50480 on 2011-01-13.

This Technical Report supersedes R064-003:1998.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

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Introduction

The harmonised rules for the erection of electrical low voltage installations, HD 384/HD 60364, require selection, dimensioning and calculation for the components of an electrical installation.

In complex installations long and detailed calculations may be needed. The rules of HD 384/HD 60364 give the basic principles without the details necessary for an accurate application.

Computers with appropriate software enable the applicable rules for the determination of conductor cross-section area and selection of protective devices to be applied readily.

It is important that the results of such software programs are in accordance with the harmonised rules.

Therefore this Technical Report defines the different reference parameters necessary for the calculation of the cross-sectional area of the conductors and for the selection of the protective devices. It also gives the reference methods for calculation according to the different safety rules defined in the Harmonisation Documents of the series HD 384/HD 60364.

1 Scope

This Technical Report applies to low-voltage installations with a nominal system frequency of 50 Hz in which the circuits consist of insulated conductors, cables or busbar trunking systems.

It defines the different parameters used for the calculation of the characteristics of electrical wiring systems in order to comply with rules of HD 384/HD 60364.

These rules are mainly the following:

- current-carrying capacities of the conductors;
- characteristics of protective devices in regard to protection against overcurrent;
- verification of thermal stress in conductors due to short-circuit current or earth fault current;
- fault protection (protection against indirect contact) in TN systems and IT systems;
- limitation of voltage drop;
- verification of mechanical stresses during short-circuit in busbar trunking systems (BTS) according to EN 60439-2 or powertrack systems according to EN 61534 series.

The calculations provided in this Technical Report are only applicable where the characteristics of the circuits are known.

For the purpose of this document, when referring to Busbar Trunking Systems, Powertrack Systems are also considered.

NOTE 1 Mechanical stress during short-circuit is covered by IEC 60865.

NOTE 2 In general these calculations concern supply by HV/LV transformer, but they are also applicable to supply by LV/LV transformer and LV back-up generators.

NOTE 3 Effects of harmonics currents are not covered by this document.

This Technical Report is also applicable for checking the compliance of the results of calculations performed by software programs for calculation of cross-sectional area of insulated conductors, cross-sectional area of cables and characteristics for selection of busbar trunking systems with HD 384/HD 60364.

2 Reference documents

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.

EN 60076 series		Power transformers (IEC 60076 series)
EN 60228		Conductors of insulated cables (IEC 60228)
EN 60269 series		Low voltage fuses (IEC 60269 series)
EN 60269-1		Low-voltage fuses - Part 1: General requirements (IEC 60269-1)
HD 60269-2		Low-voltage fuses - Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) - Examples of standardized systems of fuses A to J (IEC 60269-2)
HD 60269-3		Low-voltage fuses - Part 3: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household or similar applications) - Examples of standardized systems of fuses A to F (IEC 60269-3)
EN 60439-1	1999	Low-voltage switchgear and controlgear assemblies - Part 1: Type-tested and partially type-tested assemblies (IEC 60439-1:1999)
EN 60439-2	2000	Low-voltage switchgear and controlgear assemblies - Part 2: Particular requirements for busbar trunking systems (busways) (IEC 60439-2:2000)
EN 60898 series		Electrical accessories - Circuit-breakers for overcurrent protection for household and similar installations (IEC 60898 series)
EN 60947-2		Low-voltage switchgear and controlgear - Part 2: Circuit-breakers (IEC 60947-2)
EN 61439-1	2009	Low-voltage switchgear and controlgear assemblies - Part 1: General rules (IEC 61439-1:2009, mod.)
EN 61534 series		Powertrack systems (IEC 61534 series)
HD 384/HD 60364 series		Low-voltage electrical installations (IEC 60364 series)
HD 60364-4-41	2007	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock (IEC 60364-4-41:2005, mod.)
HD 60364-4-43	2010	Low-voltage electrical installations - Part 4-43: Protection for safety - Protection against overcurrent (IEC 60364-4-43:2008, mod. + corrigendum October 2008)
HD 60364-5-52,	2010	Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems (IEC 60364-5-52:2009, mod.)
HD 384-5-54		Electrical installation of buildings - Part 5: Selection and erection of electrical equipment - Chapter 54: Earthing arrangements and protective conductors (IEC 60364-5-54)
IEC 60909 series		Short-circuit currents in three-phase a.c. systems (IEC 60909 series)

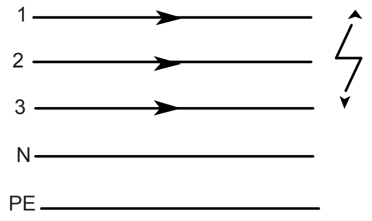
3 Symbols

In this Technical Report, the following symbols are used:

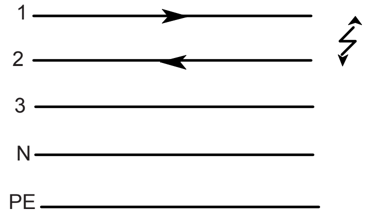
I_2	*Current ensuring effective operation in conventional time of the protective device and generally given in the product standard, [A]*
I_B	*Design current of the circuit being considered, [A](IEV 826-11-10)*
I_{ef}	*Earth fault current, [kA]*
I_n	*Nominal current of the protective device (fuse rating or breaker setting), [A]*
I_{nc}	*Rated current of busbar trunking system, at an ambient temperature of 30 °C,[A]*
I_p	*Maximum peak value of highest short-circuit current,[kA]*
I''_{kQ}	*Initial symmetrical short-circuit current at the feeder connection point Q [kA]*
I_{k1}	*Steady state short-circuit current for a line-to-neutral short circuit [kA]*
I_{k2}	*Steady state short-circuit current for a line-to-line short circuit [kA]*
I_{k3}	*Steady state short-circuit current for a three line short circuit [kA]*
NOTE 1	In some cases the I_{k1} can be higher than the I_{k3} (e.g. at the terminals of the delta-star transformer).
I_Z	*Continuous current-carrying capacity of cable, insulated conductors or busbar trunking system as applied in a circuit [A]*
$(I_0^2 \cdot t_0)$	*Thermal stress capacity of line, neutral or PE (PEN) conductor given in general for one second, [A².s], (IEV 447-07-17)*
$(I_{cw}^2 \cdot t_{cw})$	*Thermal stress capacity of line, neutral or PE (PEN) conductor given in general for one second for busbar trunking systems, [A².s], (EN 60439-2, 4.3)*
l_1	*Route length (insulated conductors and cables), [m],* *subscript u: upstream* *subscript d: downstream*
l_2	*Length of BTS (Busbar Trunking System), [m]* *subscript u: upstream* *subscript d: downstream*
R_C	*Resistance of the conductor between the transformer and the main switchboard [mΩ]*
$R_{c1\ ph}$	*Resistance of line conductor per metre, consisting of insulated conductor or cable, at steady-state operating temperature, [mΩ/m]*
$R_{c1\ N}$	*Resistance of neutral conductor per metre, consisting of insulated conductor or cable, at steady-state operating temperature, [mΩ/m]*
$R_{c1\ PE}$	*Resistance of protective earthing conductor per metre, consisting of insulated conductor or cable, at steady-state operating temperature, [mΩ/m]*
R_N	*Resistance of the neutral conductor upstream of the circuit being considered,* $R_N = \sum R_{neutral}$ *, [mΩ]*
R_{PE}	*Resistance of the protective conductor from the main equipotential bonding to the origin of the circuit being considered,* $R_{PE} = \sum R_{protective\,conductor}$ *, [mΩ]*
R_{PEN}	*Resistance of the PEN conductor from the main equipotential bonding to the origin of the circuit being considered,* $R_{PEN} = \sum R_{PEN\ conductor}$ *, [mΩ]*

R_{Q}	*Resistance of the HV network, [mΩ]*
R_{SUP}	*Resistance of the LV upstream network, [mΩ]*
R_{T}	*Resistance of the transformer, [mΩ]*
$R_{\mathrm{b0\ ph}}$	*Mean ohmic resistance of BTS (BusbarTrunking System) per meter, per line, at 20 °C, [mΩ / m]*
$R_{\mathrm{b1\ ph}}$	*Mean ohmic resistance of BTS per meter, per line, at rated current I_{nc}, at the steady-state operating temperature, [mΩ / m]*

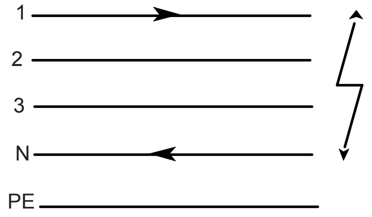
Symbols used for resistances in the context of short-circuits in busbar trunking systems



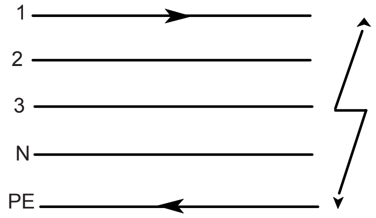
R_{bxph} Three-line short-circuit



$R_{\mathrm{bxph\ ph}}$ Line to line short-circuit between L1 and L2, note may be between any two lines



$R_{\mathrm{bxph\text{-}N}}$ Line to neutral short-circuit between L1 and N



$R_{\mathrm{bxph\text{-}PE}}$ fault between L1 and PE

NOTE 2 The value of x depends on the circuit configuration and on the type of protective device, see Table 5.

NOTE 3 For busbar trunking systems the subscript ph is used in order to align with the symbols used in EN 60439-2.

R_{b0}	*Resistive term of mean line-line, line-neutral or line-PE (-PEN) BTS loop impedance per metre, at 20 °C, [mΩ / m]*
R_{b1}	*Resistive term of mean line-line, line-neutral or line-PE (-PEN) BTS loop impedance per metre, at rated current I_{nc}, at the steady-state operating temperature, [mΩ / m]*
R_{b2}	*Resistive term of mean line-line, line-neutral or line-PE (-PEN) BTS loop impedance per metre, at the mean temperature between the operating temperature at rated current Inc, and the maximum temperature under short-circuit conditions, [mΩ / m]*
R_{SUP}	*Resistance from the LV side of the upstream network (LV + MV) upstream the main switchboard, [mΩ]*

R_U	*Resistance of line conductors upstream of the circuit being considered up to the main switchboard*

$$R_\mathrm{u} = \sum R_\mathrm{line}\text{ , }[\mathrm{m}\Omega]$$

S	*Cross-sectional area of conductors, [mm²]*
S_N	*Cross-sectional area of neutral conductor, [mm²]*
S_PE	*Cross-sectional area of protective conductor, [mm²]*
S_PEN	*Cross-sectional area of PEN conductor, [mm²]*
S_kQ	*Short-circuit power of the high-voltage network, [kVA]*
S''_kQ	*Initial symmetrical short-circuit power* of the high-voltage network, *[kVA]*
S_rG	*Rated apparent power of a generator [kVA]*
S_rM	*Rated apparent power of the motor, [kVA]*
S_rT	*Rated apparent power of the transformer [kVA]*
S_ph	*Cross-sectional area of line conductor, [mm²]*
t_r	*Rated transformation ratio at which the on-load tap-changer is in the main position*
U_o	*Line to neutral nominal voltage of the installation, [V]*
U_n	*Line to line nominal voltage of the installation, [V]*
U_nQ	*Nominal system voltage at the feeder connection point Q (HV side), [V]*
U_rT	*Rated voltage of the transformer on the low voltage side, [V]*
X_C	*Reactance of the conductor between the transformer and the main switch board [mΩ]*
$X_\mathrm{C\ ph}$	*Reactance of line conductor per metre, consisting of insulated conductor or cable, [mΩ/m]*
X'_d	*Transient reactance on direct axis [mΩ]*
x'_d	*Transient reactance on direct axis [%]*
X_N	*Reactance of the neutral conductor upstream of the circuit being considered,*

$$X_N = \sum X_{neutral}\quad\text{, }[\mathrm{m}\Omega]$$

X_0	*Zero-sequence reactance [mΩ]*
x_0	*Zero-sequence reactance [%]*
X_PE	*Reactance of the protective conductor from the main equipotential bonding to the origin of the circuit being considered,*

$$X_{PE} = \sum X_{protective\,conductor}\quad\text{,}[\mathrm{m}\Omega]$$

X_PEN	*Reactance of the PEN conductor from the main equipotential bonding to the origin of the circuit being considered,*

$$X_{PEN} = \sum X_{PEN\,conductor}\quad\text{, }[\mathrm{m}\Omega]$$

X_Q	*Reactance of the HV network, [mΩ]*
X_SUP	*Reactance from the LV side of the upstream network (LV + MV) upstream the main switchboard, [mΩ]*
X_T	*Reactance of the transformer, [mΩ]*
X_b	*Reactance term of mean line-line, line-neutral or line-PE (-PEN) BTS loop impedance per metre, [mΩ / m]*
$X_\mathrm{b\ ph}$	*Mean reactance of BTS line conductor, per meter, [mΩ / m]*

X_U	*Reactance of line conductors upstream of the circuit being considered up to the main switchboard,*

$$X_U = \sum X_{line} \text{ , } [m\Omega]$$

Z_C	*Impedance of the conductor between the transformer or the generator and the main switch board [mΩ]*
Z_G	*Impedance of the generator [mΩ]*
Z_Q	*Impedance of the HV supplier network, [mΩ]*

$$Z_Q = \sqrt{R_Q^2 + X_Q^2}$$

Z_{Qt}	*Positive-sequence equivalent short circuit impedance referred to the low-voltage side of the transformer*
Z_{SUP}	*Impedance from the LV side of the upstream network (LV + MV) upstream the main switchboard, [mΩ]*
Z_T	*Impedance of the transformer, [mΩ]*

$$Z_T = \sqrt{R_T^2 + X_T^2}$$

Z_U	*Impedance of line conductors upstream of the circuit being considered up to the main switchboard, [mΩ]*

$$Z_U = \sqrt{(\sum R_{line}^2 + \sum X_{line}^2)}$$

NOTE These impedances are shown in Fig 1

c	*Voltage factor according to IEC 60909*
n_N	*Number of neutral conductors in parallel*
n_{PE}	*Number of protective conductors in parallel*
n_{PEN}	*Number of PEN conductors in parallel*
n_{ph}	*Number of line conductors in parallel*
x	*Reactance per metre of conductors, [mΩ / m]*
ρ_0	*Resistivity of conductors at 20 °C, [mΩ·mm² / m]*
ρ_1	*Resistivity of conductors at the maximum permissible steady-state operating temperature, [mΩ·mm² / m]*
ρ_2	*Resistivity of conductors at the mean temperature between steady-state temperature and final short-circuit temperature, [mΩ·mm² / m]*
ρ_3	*Resistivity of separate PE conductors at the mean temperature between ambient and final short-circuit temperature, [mΩ·mm² / m]*
θ	*Temperature, [ºC]*

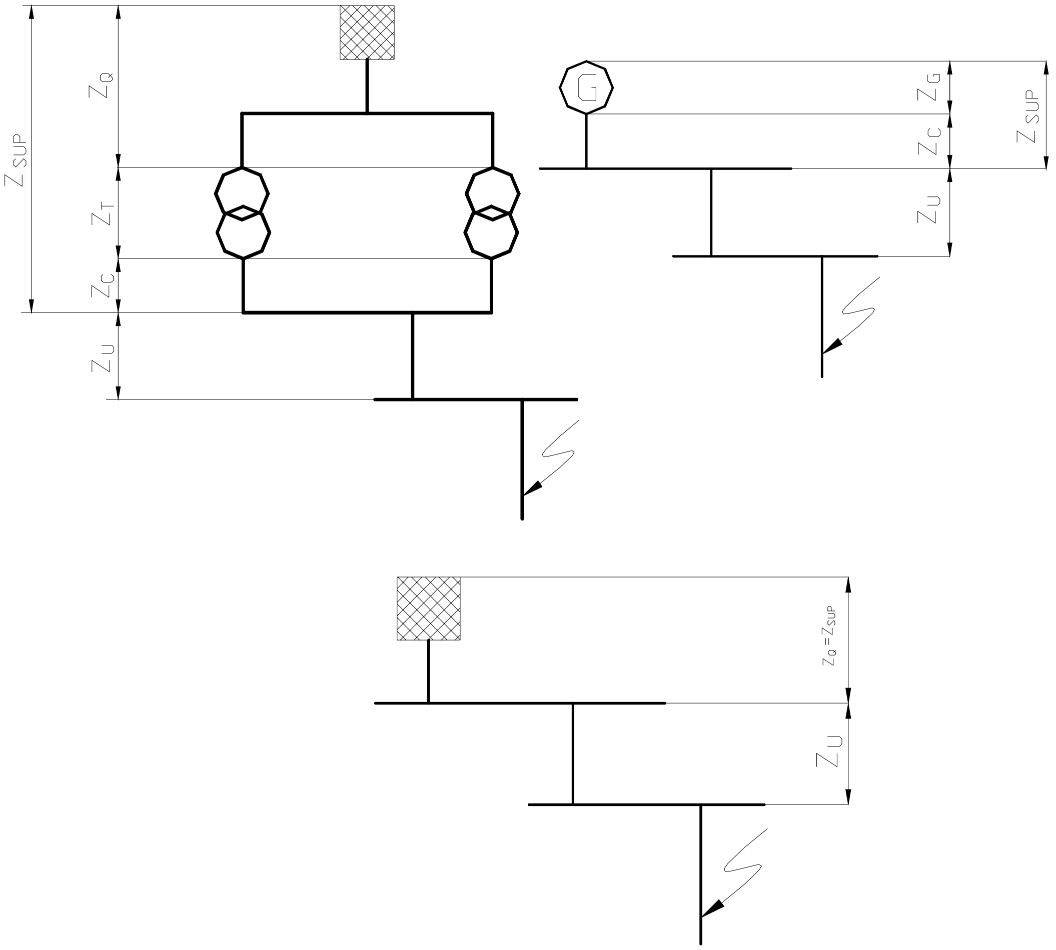


Figure 1 – Examples of installation configurations and impedances used in this document

4 Parameters

4.1 General

Table 1 − Resistivity at 20 °C in accordance with IEC 60909, in mΩ·mm² / m

	Copper	Aluminium
ρ_0	18,51	29,41

NOTE 1 For the conductor resistances when dealing with cables, Annex A may also be used.

Table 2 − Resistivity at various temperatures

	Thermoplastic 70 °C (PVC)		Thermosetting 90 °C (EPR or XLPE)	
	Resistivity	Temperature	Resistivity	Temperature
ρ_0	1,00 ρ_0	20 °C	1,00 ρ_0	20 °C
ρ_1	1,20 ρ_0	70 °C	1,28 ρ_0	90 °C
ρ_2 $\leq 300 \mathrm{mm}^2$	1,38 ρ_0	$\frac{160+70}{2}=115°$	1,60 ρ_0	$\frac{250+90}{2}=170°$
ρ_2 $> 300 \mathrm{mm}^2$	1,34 ρ_0	$\frac{140+70}{2}=105°$		
ρ_3 $\leq 300 \mathrm{mm}^2$	1,30 ρ_0	$\frac{160+30}{2}=95°$	1,48 ρ_0	$\frac{250+30}{2}=140°$
ρ_3 $> 300 \mathrm{mm}^2$	1,26 ρ_0	$\frac{140+30}{2}=85°$		

The above factors are obtained using the following equation:

$$\rho_\theta = \rho_0 \, [1 + 0{,}004 \cdot (\theta - 20)]$$

where

θ is the conductor temperature

Table 3 − Reactance per metre of conductors of cables (x)

	x $[m\Omega / m]$
Multicore cables or single core cables in trefoil arrangement	0,08
Flat touching single core cables	0,09
Flat spaced single core cables	0,13

NOTE 2 Values for armoured cable should be obtained from the manufacturer.

NOTE 3 The reactance values given are for single-line system, they can be used as average values for a three-line system.

NOTE 4 For spaced single core cables, the distance from centre to centre is assumed to be two times the overall cable diameter.

NOTE 5 More precise values may be obtained from IEC/TR 60909-2 or from manufacturers.

4.2 Conductor resistances

Conductor resistances per meter at 20 °C are given in Annex A.

For the calculations set out in this Technical Report, conductor resistances per metre for sizes up to 300 mm^2, may be obtained from the following equations:

Line conductor	**Neutral conductor**	**Protective conductor**	
$R_{\mathrm{c0ph}} = \frac{\rho_0}{S_{\mathrm{ph}} \cdot n_{\mathrm{ph}}}$	$R_{\mathrm{c0N}} = \frac{\rho_0}{S_{\mathrm{N}} \cdot n_{\mathrm{N}}}$	$R_{\mathrm{c0PE}} = \frac{\rho_0}{S_{\mathrm{PE}} \cdot n_{\mathrm{PE}}}$	or $R_{\mathrm{c0PEN}} = \frac{\rho_0}{S_{\mathrm{PEN}} \cdot n_{\mathrm{PEN}}}$
$R_{\mathrm{c1ph}} = \frac{\rho_1}{S_{\mathrm{ph}} \cdot n_{\mathrm{ph}}}$	$R_{\mathrm{c1N}} = \frac{\rho_1}{S_{\mathrm{N}} \cdot n_{\mathrm{N}}}$	$R_{\mathrm{c1PE}} = \frac{\rho_1}{S_{\mathrm{PE}} \cdot n_{\mathrm{PE}}}$	or $R_{\mathrm{c1PEN}} = \frac{\rho_1}{S_{\mathrm{PEN}} \cdot n_{\mathrm{PEN}}}$
$R_{\mathrm{c2ph}} = \frac{\rho_2}{S_{\mathrm{ph}} \cdot n_{\mathrm{ph}}}$	$R_{\mathrm{c2N}} = \frac{\rho_2}{S_{\mathrm{N}} \cdot n_{\mathrm{N}}}$	$R_{\mathrm{c2PE}} = \frac{\rho_2}{S_{\mathrm{PE}} \cdot n_{\mathrm{PE}}}$	or $R_{\mathrm{c2PEN}} = \frac{\rho_2}{S_{\mathrm{PEN}} \cdot n_{\mathrm{PEN}}}$
		$R_{\mathrm{c3PE}} = \frac{\rho_3}{S_{\mathrm{PE}} \cdot n_{\mathrm{PE}}}$	

NOTE The current sharing has been considered as equal between several conductors in parallel. The current sharing may not be equal between several conductors in parallel of large cross-section e.g. greater than 240 mm², hence simple division by the number of conductors may not be suitable (see IEC 60287-1-3).

4.3 Conductor reactances

Conductor reactances per meter are obtained from the following equations:

Three-line or line to line $X_{\mathrm{c}} = \frac{x}{n_{\mathrm{ph}}}$

Line to neutral (or PE or PEN) $X_{\mathrm{cph}} = \frac{x}{n_{\mathrm{ph}}}$

$$X_{\mathrm{cN}} = \frac{x}{n_{\mathrm{N}}}$$

$$X_{\mathrm{cPE}} = \frac{x}{n_{\mathrm{PE}}}$$

$$X_{\mathrm{cPEN}} = \frac{x}{n_{\mathrm{PEN}}}$$

NOTE 1 For conductors having a cross-sectional area of less than 25 mm², the reactance is much smaller than the resistance and hence it can be ignored for the calculations set out in this Technical Report and made manually.

NOTE 2 Although it is usually convenient to consider the value of inductive reactance of each conductor of a earth fault current loop separately as done in this Technical Report, such values do not truly exist as independent quantities, as inductive reactance is a function of all the conductors in close proximity.

Consequently, the value of inductive reactance for a conductor is liable to be different for the various fault conditions (three-line fault, line-to-earth fault, etc.) for which the conductor forms part of the earth fault current loop.

5 Characteristics of installations

Table 4 − Selection of resistivity and reactance for insulated conductors and cables

			INSULATED CONDUCTORS AND CABLES					
			RESISTIVITY					**REACTANCE**
RULES	**CURRENTS**	**CIRCUITS**	UPSTREAM CIRCUITS	CIRCUIT				All circuits
				Distribution circuits		Final circuit		
MAXIMUM SHORT-CIRCUIT CURRENT	$I_{k3\ max}$	3 Line	ρ_0	ρ_0		ρ_0		x
	$I_{k2\ max}$	Line to line	ρ_0	ρ_0		ρ_0		x
	$I_{k1\ max}$	Line to neutral	ρ_0	ρ_0		ρ_0		x
	NATURE OF THE PROTECTIVE DEVICE			Fuse	Circuit breaker	Fuse	Circuit breaker	
MINIMUM SHORT - CIRCUIT CURRENT	$I_{k2\ min}$	Line to line	ρ_1	ρ_2	ρ_1	ρ_2	ρ_1	x
	$I_{k1\ min}$	Line to neutral	ρ_1	ρ_2	ρ_1	ρ_2	ρ_1	x
EARTH FAULT CURRENT	I_{ef}	Line to PEN / Line to PE	ρ_1	ρ_2	ρ_1 [b]	ρ_1 [a]	ρ_1	x
		Line to reduced PEN / Line to reduced PE	ρ_1	ρ_2	ρ_1 [b]	ρ_2	ρ_1 [a]	x
		Line to separate PE:						
		for line	ρ_1	ρ_2	ρ_1	ρ_1	ρ_1	x
		for PE	ρ_1	ρ_3	ρ_1	ρ_1	ρ_1	x
		for reduced PE	ρ_1	ρ_3	ρ_1	ρ_2	ρ_1 [a]	x
VOLTAGE DROP	I_B	All live conductors	ρ_1	ρ_1	ρ_1	ρ_1	ρ_1	x

[a] for circuits with a disconnecting time greater than the value given in Table 10 use ρ_2 .

[b] use ρ_2 if a time delayed-circuit breaker is used.

Table 5 − Selection of resistance and reactance for busbar trunking systems

			BUSBAR TRUNKING SYSTEMS					
			RESISTANCE					**REACTANCE**
RULES	**CURRENTS**	**CIRCUITS**	UPSTREAM CIRCUITS	CIRCUIT				All circuits
				Distribution circuit		Final circuit		
MAXIMUM SHORT-CIRCUIT CURRENT	$I_{k3\ max}$ $I_{k2\ max}$ $I_{k1\ max}$	Line Line to line Line to neutral	$R_{b0\ ph}$ $R_{b0\ ph\ ph}$ $R_{b0\ ph\ N}$	$R_{b0\ ph}$ $R_{b0\ ph\ ph}$ $R_{b0\ ph\ N}$		$R_{b0\ ph}$ $R_{b0\ ph\ ph}$ $R_{b0\ ph\ N}$		$X_{b\ ph}$ $X_{b\ ph\ ph}$ $X_{b\ ph\ N}$
	NATURE OF THE PROTECTIVE DEVICE:			Fuse	Circuit-breaker	Fuse	Circuit-breaker	
MINIMUM SHORT – CIRCUIT CURRENT	$I_{k2\ min}$ $I_{k1\ min}$	Line to line Line to neutral	$R_{b1\ ph\ ph}$ $R_{b1\ ph\ N}$	$R_{b2\ ph\ ph}$ $R_{b2\ ph\ N}$	$R_{b1\ ph\ ph}$ $R_{b1\ bph\ N}$	$R_{b2\ ph\ ph}$ $R_{b2\ ph\ N}$	$R_{b1\ ph\ ph}$ $R_{b1\ ph\ N}$	$X_{b\ ph\ ph}$ $X_{b\ ph\ N}$
EARTH FAULT CURRENT	I_{ef}	Line to PEN Line to PE	$R_{b1\ ph\ PEN}$ $R_{b1\ ph\ PE}$	$R_{b2\ ph\ PEN}$ $R_{b2\ ph\ PE}$	$R_{b1\ ph\ PEN}$ [b] $R_{b1\ ph\ PE}$ [b]	$R_{b1\ ph\ PEN}$ [a] $R_{b1\ ph\ PE}$ [a]	$R_{b1\ ph\ PEN}$ $R_{b1\ ph\ PE}$	$X_{b\ ph\ PEN}$ $X_{b\ ph\ PE}$
VOLTAGE DROP	I_B	Line Line to neutral	$R_{b1\ ph}$ $R_{b1ph\ N}$	$R_{b1\ ph}$ $R_{b1\ ph\ N}$	$R_{b1\ ph}$ $R_{b1\ ph\ N}$	$R_{b1\ ph}$ $R_{b1\ ph\ N}$	$R_{b1\ ph}$ $R_{b1\ ph\ N}$	$X_{b\ ph}$ $X_{b\ ph\ N}$

[a] for circuits with a disconnecting time greater than the value given in Table 10 use R_{b2}.

[b] use ρ_2 if a time delayed-circuit breaker is used.

Table 6 − Elements to take into account when calculating maximum and minimum short circuit currents and earth fault currents

RULES	CURRENTS	CIRCUITS	SUPPLY OF CIRCUITS	
			Circuit supplied by transformer(s)	Circuit supplied by transformer(s) or replacement/safety generator
Maximum Short-circuit current	I_{k3}	3 Line	All transformers in parallel	All transformers in parallel
	I_{k2}	2 Line		
	I_{k1}	Line to neutral		
Minimum Short-circuit current	I_{k2min}	2 Line	1 transformer only (lowest power)	Generator
	I_{k1min}	Line to neutral		
Fault current	I_{ef}	Line to PE	1 transformer only (lowest power)	Generator

6 Characteristics of the supply source

6.1 Voltage

The reference parameter is the line to neutral nominal voltage $U_\mathrm{o} = U_\mathrm{n} / \sqrt{3}$, multiplied by the factor c.

The voltage factor *c* is introduced to take account of voltage variations depending on time and place, changing of transformer taps and other considerations. The values of *c* for the worst case condition in a low voltage installation are given in Table 7, derived from IEC 60909, Table 1.

The factor *c* is not intended to take account of the fault impedance. This Technical Report assumes zero fault impedance.

Table 7 − Voltage factor *c*

Nominal voltage	Voltage factor c	
	c_max	c_min
100 V to 1 000 V	1,1	0,95

6.2 Supply by HV/LV transformers

6.2.1 General

When the installation includes the supply from an HV network, the impedance of the HV network and the HV/LV transformer must be taken into account when calculating short-circuit and earth fault currents.

6.2.2 Impedance of a HV/LV network

The impedance of the HV network seen from the LV side may be obtained from the electricity supply company or by measurement or by calculation as follows:

$$Z_\mathrm{Qt} = \frac{c \cdot U_\mathrm{nQ}^2}{S''_\mathrm{kQ}} \cdot \left(\frac{1}{t_\mathrm{r}^2} \right) \quad \text{(1a)or} \quad Z_\mathrm{Qt} = \frac{c \cdot U_\mathrm{nQ}}{\sqrt{3} \cdot I''_\mathrm{kQ}} \cdot \left(\frac{1}{t_\mathrm{r}^2} \right) \text{(1b)}$$

$R_\mathrm{Q} = 0{,}100\, X_\mathrm{Q}$

$X_\mathrm{Q} = 0{,}995\, Z_\mathrm{Q}$ according to IEC 60909, in the absence of precise information from the electricity supply company.

NOTE Where Z_Q is to be used for calculating the maximum short-circuit current, $S_\mathrm{kQ\,max}$, I''_kQmax and c_max should be applied.

Where Z_Q is to be used for calculating the minimum short-circuit current, $S_\mathrm{kQ\,min}$, I''_kQmin and c_min should be applied.

6.2.3 Impedance of a transformer

$$Z_\mathrm{T} = \frac{U_{rT}^2}{S_\mathrm{rT}} \cdot \frac{u_\mathrm{kr}}{100} \quad \text{(2a)}$$

$$R_\mathrm{T} = \frac{u_\mathrm{Rr}}{100} \frac{U_\mathrm{rT}^2}{S_\mathrm{rT}} = \frac{P_\mathrm{krT}}{3 I_\mathrm{rT}^2} \quad \text{(2b)}$$

$$X_{\mathrm{T}} = \sqrt{Z_{\mathrm{T}}^2 - R_{\mathrm{T}}^2} \quad (2c)$$

u_{kr}:Short-circuit voltage [%], according to EN 60076.

u_{Rr}: Rated resistive component of the short-circuit voltage [%]

P_{krT}: total loss of the transformer in the windings at rated current [kW]

Where the value of U_{rT} is not known, it may be assumed to be 1,05 U_{n}.

The resistance and reactance of the transformer may be obtained from the manufacturer.

In the absence of more precise information, the following values may be used: $R_{\mathrm{T}} = 0{,}31\ Z_{\mathrm{T}}$

$X_{\mathrm{T}} = 0{,}95\ Z_{\mathrm{T}}$

NOTE This equation is also applicable to LV/LV transformer which may, for example, be used to change the neutral regime.

In case of several transformers in parallel having the same rated short-circuit voltage and preferably the same power rating, calculations for the maximum short-circuit current are made with the total number of transformers being able to operate simultaneously.

6.3 Supply by generators

6.3.1 General

When the installation is supplied by generators, the impedances to be taken into consideration are:

6.3.2 Transient reactance on direct axis, X'_{d}

$$X'_{\mathrm{d}} = \frac{(U_{\mathrm{n}})^2}{S_{\mathrm{rG}}} \cdot \frac{x'_{\mathrm{d}}}{100} \quad (3)$$

In the absence of more precise information, the transient reactance on direct axis may be taken as equal to 30 %

6.3.3 Zero-sequence reactance X_0

$$X_{\mathrm{o}} = \frac{(U_{\mathrm{n}})^2}{S_{\mathrm{rG}}} \cdot \frac{x_0}{100} \quad (4)$$

The reactances referred to above may be obtained from the manufacturer.

In the absence of more precise information, the zero-sequence reactance may be taken as equal to 6 %

6.4 Contribution of asynchronous motors

6.4.1 General

Where the installation is not supplied through a LV network, the contribution from asynchronous motors may need to be taken into account.

In the case of a short-circuit, an asynchronous motor can be considered as being a generator, for a short period of time. Although this duration is small (a few periods of the signal’s fundamental frequency), motors can increase significantly the maximum short circuit current and, in such a case, have to be taken into account.

Motors controlled by static variable speed drives (e.g. static inverters) do not contribute to the short-circuit current.

6.4.2 Cases to be neglected

The contribution of asynchronous motors in low-voltage power supply systems to the short-circuit current may be neglected if the total power of motors running simultaneously is lower than 25 % of the total power of transformers

$$S_{\mathrm{rM}} = \sum_{n=1}^{n_{ms}} S_{\mathrm{rM}} \leq 25\% \cdot \sum S_{\mathrm{rT}}$$

where

n_{ms} is the number of motors running simultaneously

$S_{\mathrm{M}}$is the sum of the rated apparent power on the electrical side of the motors (S_{rM}) running simultaneously [kVA]

6.4.3Case where motor’s contribution has to be taken into account

If $S_{\mathrm{rM}} > 25\% \cdot \sum S_{\mathrm{rT}}$, all the asynchronous motors that run simultaneously can be considered as a supplementary supply in parallel with transformer(s).

A good approximation, to take into account the contribution of motors to the maximum short-circuit current, is to multiply R_{SUP} and X_{SUP} by a coefficient k_{M}. The values of k_{M} are given in Table 8.

Table 8 − Values of k_{M}

Type of supply	Values of k_{M}	
	$S_{\mathrm{rM}} \leq 25\% \cdot \sum S_{\mathrm{rT}}$	$S_{\mathrm{rM}} > 25\% \cdot \sum S_{\mathrm{rT}}$
Supply through transformer(s)	1	$\frac{5\sum S_{\mathrm{rT}}}{5\sum S_{\mathrm{rT}} + 1.1 \cdot S_{\mathrm{rM}}}$
LV Supply	1	1

6.5 LV supply

Information regarding the impedance of the low-voltage supply may be obtained from the electricity supply company. Because public supply systems change to reflect growth or decline in the electricity consumption for the local network and to meet day to day demands a single value for the supply impedance may not be available. In most cases, the likely maximum and minimum values can be obtained. Where separate values of R_{SUP} and X_{SUP} are not available, the impedance Z_{SUP} is substituted for R_{SUP} in the equations with $X_{\mathrm{SUP}} = 0$.

6.6 Capacitors

Regardless of the time of short-circuit occurrence, the discharge current of the capacitors may be neglected for the calculation of the peak short-circuit currents

7 Characteristics of protective devices

7.1 Circuit-breakers

For protection against short-circuit and earth fault currents, characteristics taken into consideration are:

- the instantaneous or the short time operating current for minimum short-circuit and earth fault currents;

- for maximum short-circuit current, the breaking capacity and the let-through energy (I^2t) of the circuit-breaker.

To ensure instantaneous operation of the circuit-breaker, the short-circuit or earth fault current must be greater than the short time operating current or the instantaneous operating current. Circuit-breaker characteristics may be obtained from the manufacturer.

For circuit-breakers complying with EN 60898, the upper limit of the specified instantaneous operating current is equal to

-$5\ I_n$ for type B circuit-breakers;

-$10\ I_n$ for type C circuit-breakers;

-$20\ I_n$ for type D circuit-breakers.

For circuit-breakers complying with EN 60947-2, the maximum short-time or instantaneous operating current is at most equal to 1,2 times the operating current setting, this takes into account tolerances of setting equal to 20 %.

7.2 Fuses

Fuses comply with EN 60269-1, and HD 60269-2 or HD 60269-3.

For fuses other than gG, the time current characteristics should be obtained from national standards.

Characteristics for gG and aM fuses correspond approximately to the equation:

$$t = \left(\frac{I_{1s}}{I}\right)^n \quad (5a)$$

$$I = \frac{I_{1s}}{\sqrt[n]{t}} \quad (5b)$$

where

n is equal to 4 for type gG fuses, and to 4,55 for type aM fuses;

I_{1s} is the current that melts the fuse in one second;

t is the time in seconds.

This equation is used for determining the time of operation of a fuse (t) at the prospective fault current I. This equation is approximate and should only be used for short time (t), for example, less than 2 s for a 6 A gG fuse and less than 5 s for a 80 A gG fuse (see time-current curve for gG fuse link in HD 60269-2).

8 Protection against overload currents

8.1 Current-carrying capacity

a) Values of current-carrying capacity and correction factors for insulated conductors and cables are given in HD 60364-5-52.

b) Current-carrying capacities for cable types and insulation conditions not covered by the above publications should be obtained from the national standards or the manufacturer.

8.2 Coordination between conductors and overload protective devices

The value of current-carrying capacity of conductors and the value of rated current of busbar trunking systems are calculated in relation to the rated current of a fuse or the current setting of a circuit-breaker used for protection against overload by the following formula:

$$I_B \leq I_n \leq I_Z \quad (6)$$

$$I_2 \leq 1{,}45\, I_Z \quad (7)$$

NOTE 1 For circuit-breakers complying with EN 60898 or EN 60947-2 and gG fuses complying with HD 60269-2 and HD 60269-3, compliance with Equation (6) is deemed to satisfy the requirement of Equation (7).

NOTE 2 Where four or more conductors have to be connected in parallel consideration should be given to the use of busbar trunking systems.

9 Determination of breaking capacity of protective devices

9.1 General

The breaking capacity of the protective device (fuse, circuit-breaker) shall be at least equal to the maximum prospective short-circuit current at the place of its installation (see HD 60364-4-43). This requirement does not apply where another device or devices, having the necessary breaking capacity, is installed on the supply side, and the characteristics of the devices are co-ordinated so that the energy let-through of the devices does not exceed that which can be withstood, without damage, by the device or devices on the load side.

In case of several transformers in parallel, calculations for the maximum short-circuit current are to be done with the total number of transformers being able to operate simultaneously. The following equations apply only if each transformer has the same coupling, the same rated short-circuit voltage and the same power.

NOTE In the case where motor's contribution is to be taken into account, it is recommended to verify the correct selection of the making capacity of the circuit breakers.

9.2 Three line maximum short-circuit current

In general, the maximum prospective short-circuit current is equal to the symmetrical three-line short-circuit current I_{k3}. For a short-circuit between all three lines, the maximum prospective short-circuit current will be when the short-circuit occurs at the terminals of the protective device and when the upstream circuits are at the conventional ambient temperature of 20 °C.

The three-line short-circuit current I_{k3} is equal to:

$$I_{k3\,\mathrm{max}} = \frac{c_{\mathrm{max}} \cdot U_0}{Z} = \frac{c_{\mathrm{max}} \cdot U_0}{\sqrt{\left(k_M \cdot R_{\mathrm{SUP}} + R_{\mathrm{U}} + R_{0\,\mathrm{ph}}\right)^2 + \left(k_M \cdot X_{\mathrm{SUP}} + X_{\mathrm{U}} + X_{\mathrm{ph}}\right)^2}} \tag{8}$$

where $U_0 = \frac{U_{\mathrm{n}}}{\sqrt{3}}$

NOTE 1The objective of the coefficient k_{M} is described under 6.4.3.

a)for insulated conductors and cables: $R_{0\,\mathrm{ph}} = R_{\mathrm{c0\,ph}} \cdot l_{1\mathrm{u}}$, $X_{\mathrm{ph}} = X_{\mathrm{c}} \cdot l_{1\mathrm{u}}$

b)for busbar trunking systems: $R_{0\,\mathrm{ph}} = R_{\mathrm{c0\,ph}} \cdot l_{1\mathrm{u}} + R_{\mathrm{b0\,ph}} \cdot l_{2\mathrm{u}}$, $X_{\mathrm{ph}} = X_{\mathrm{c}} \cdot l_{1\mathrm{u}} + X_{\mathrm{b\,ph}} \cdot l_{2\mathrm{u}}$

Where the lengths $l_{1\mathrm{u}}$ and $l_{2\mathrm{u}}$ are those related to the part of the circuit upstream of the protective device up to the busbar placed immediately upstream (cables and busbar trunking system respectively).

NOTE 2The following table give the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

		R_{SUP}	X_{SUP}
HV Supply + Transformer		$R_Q + R_T + R_C$	$X_Q + X_T + X_C$
HV Supply + Several transformers in parallel	Arrivals	$R_Q + (R_T + R_C)/(n_T - 1)$	$X_Q + (X_T + X_C)/(n_T - 1)$
	Departures	$R_Q + (R_T + R_C)/n_T$	$X_Q + (X_T + X_C)/n_T$
LV Supply		R_Q	X_Q
n_T	is the total number of transformers operating simultaneously.		
Arrival	is understood as the conductor between the transformer and the main switch board.		
Departure	is understood as all the installation downstream the main switch board.		

NOTE 3 Figure 2 gives an example of the meaning of the impedances used in this subclause.

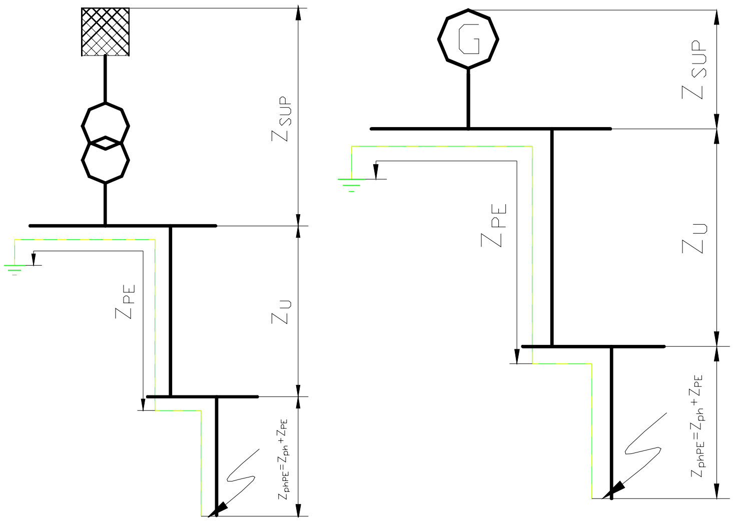


Figure 2 – Examples of installation configurations and impedances used in this clause

9.3 Line-to-line maximum short-circuit current

In general, it is not necessary to calculate the line to line maximum prospective short-circuit current because it will be lower than the three line short-circuit current.

The line to line short-circuit current, I_{k2} is equal to:

$$I_{k2\max} = \frac{c_{\max} \cdot U_0 \cdot \sqrt{3}}{2 \cdot Z} = \frac{c_{\max} \cdot U_0 \cdot \sqrt{3}}{2 \cdot \sqrt{\left(k_M \cdot R_{\text{SUP}} + R_{\text{U}} + R_{0\,\text{ph}}\right)^2 + \left(k_M \cdot X_{\text{SUP}} + X_{\text{U}} + X_{\text{ph}}\right)^2}} \qquad (9)$$

where $U_0 = \frac{U_{\text{n}}}{\sqrt{3}}$

NOTE 1The objective of the coefficient k_{M} is described under 6.4.3.

a)for insulated conductors and cables: $$R_{0\text{ph}} = R_{\text{c0ph}} \cdot l_{1\text{u}}$$ $$X_{\text{ph}} = X_{\text{c}} \cdot l_{1\text{u}}$$

NOTE 2 In the case that the complete installation is made using insulated conductors and cables, the following simplification can be used: $I_{k2max} = 0{,}86 \cdot I_{\text{k3max}}$.

b)for busbar trunking systems: $$R_{0\text{ph}} = R_{\text{c0ph}} \cdot l_{1\text{u}} + 0{,}5 R_{\text{b0ph ph}} \cdot l_{2\text{u}}$$ $$X_{\text{ph}} = X_{\text{c}} \cdot l_{1\text{u}} + 0{,}5 X_{\text{b ph ph}} \cdot l_{2\text{u}}$$

where the lengths $l_{1\text{u}}$ and $l_{2\text{u}}$ are those related to the part of the circuit upstream of the protective device up to the busbar placed immediately upstream (cables and busbar trunking system respectively).

NOTE 3The following table give the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

		R_{SUP}	X_{SUP}
HV Supply + Transformer		$R_Q + R_T + R_C$	$X_Q + X_T + X_C$
HV Supply + Several transformers in parallel	Arrivals	$R_Q + (R_T + R_C)/(n_T - 1)$	$X_Q + (X_T + X_C)/(n_T - 1)$
	Departures	$R_Q + (R_T + R_C)/n_T$	$X_Q + (X_T + X_C)/n_T$
LV Supply		R_Q	X_Q
n_T	is the total number of transformers operating simultaneously.		
Arrival	is understood as the conductor between the transformer and the main switch board.		
Departure	is understood as all the installation downstream the main switch board.		

NOTE 4 The Figure 2 gives an example of the meaning of the impedances used in this subclause.

9.4 Line-to-neutral maximum short-circuit current

This short-circuit current is calculated to determine the required breaking capacity of the protective device for single line circuits.

The current in case of short-circuit between line and neutral or PEN conductor, I_{k1} is equal to:

$$I_{k1\,max} = \frac{c_{max} \cdot U_0}{\sqrt{\left(k_M \cdot R_{SUP} + R_U + R_N + R_{0\,ph\,N}\right)^2 + \left(k_M \cdot X_{SUP} + X_U + X_N + X_{ph\,N}\right)^2}} \qquad (10)$$

where $U_0 = \frac{U_n}{\sqrt{3}}$

NOTE 1The objective of the coefficient k_M is described under 6.4.3.

a)for insulated conductors and cables: $$R_{0\,ph\,N} = \left(R_{c0\,ph} + R_{c0\,N}\right) \cdot l_{1u}$$ $$X_{ph\,N} = \left(X_{c\,ph} + X_{c\,N}\right) \cdot l_{1u}$$

or $$R_{0\,ph\,PEN} = \left(R_{c0\,ph} + R_{c0\,PEN}\right) \cdot l_{1u}$$ $$X_{ph\,PEN} = \left(X_{c\,ph} + X_{c\,PEN}\right) \cdot l_{1u}$$

b)for busbar trunking systems: $$R_{0\,ph\,N} = \left(R_{c0\,ph} + R_{c0\,N}\right) \cdot l_{1u} + R_{b0\,ph\,N} \cdot l_{2u}$$ $$X_{ph\,N} = \left(X_{c\,ph} + X_{c\,N}\right) \cdot l_{1u} + X_{b\,ph\,N} \cdot l_{2u}$$

or $$R_{0\,ph\,PEN} = \left(R_{c0\,ph} + R_{c0\,PEN}\right) \cdot l_{1u} + R_{b0\,ph\,PEN} \cdot l_{2u}$$ $$X_{ph\,PEN} = \left(X_{c\,ph} + X_{c\,PEN}\right) \cdot l_{1u} + X_{b\,ph\,PEN} \cdot l_{2u}$$

where the lengths l_{1u} and l_{2u} are those related to the circuits upstream of the protective device (cables and bus bar trunking system respectively).

NOTE 2 The following table give the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

			R_{SUP}	X_{SUP}
one transformer		Delta/Star (Dyn)	$R_Q+R_T+R_C$	$X_Q+X_T+X_C$
		Star/Star (Yyn)	$R_Q+R_T+R_C$	$X_Q+5X_T+X_C$
		Delta/Zig-Zag (Dzn)	$R_Q+R_T+R_C$	$X_Q+0,7X_T+X_C$
several transf. in parallel	arrivals	Delta/Star (Dyn)	$R_Q+(R_T+R_C)/(n_T-1)$	$X_Q+(X_T+X_C)/(n_T-1)$
		Star/Star (Yyn)	$R_Q+(R_T+R_C)/(n_T-1)$	$X_Q+(5X_T+X_C)/(n_T-1)$
		Delta/Zig-Zag (Dzn)	$R_Q+(R_T+R_C)/(n_T-1)$	$X_Q+(0,7X_T+X_C)/(n_T-1)$
	departures	Delta/Star (Dyn)	$R_Q+(R_T+R_C)/n_T$	$X_Q+(X_T+X_C)/n_T$
		Star/Star (Yyn)	$R_Q+(R_T+R_C)/n_T$	$X_Q+(5X_T+X_C)/n_T$
		Delta/Zig-Zag (Dzn)	$R_Q+(R_T+R_C)/n_T$	$X_Q+(0,7X_T+X_C)/n_T$
LV supply			R_Q	X_Q
n_T is the total number of transformers operating simultaneously *Arrival* is understood as the conductor between the transformer and the main switch board *Departure* is understood as all the installation downstream the main switch board				

NOTE 3 The Figure 2 gives an example of the meaning of the impedances used in this subclause.

10 Ability to withstand electro-dynamic stresses for busbar trunking systems

During a short-circuit, the highest force will occur at the peak value of the initial asymmetrical short-circuit current. Hence, it is the peak value of the current which is considered and not the r.m.s. value.

The peak value of the prospective short-circuit current I_p is equal to the r.m.s. short circuit current I_{k3} at the origin of the busbar trunking system multiplied by the peak factor (n) having the following value:

Table 9 − Peak factor (*n*)

r.m.s. short-circuit current	*n*
$I \leq 5\ kA$	1,5
$5\ kA < I \leq 10\ kA$	1,7
$10\ kA < I \leq 20\ kA$	2
$20\ kA < I \leq 50\ kA$	2,1
$50\ kA < I$	2,2

This table is taken from EN 60439-1:1999, 7.5.3 or EN 61439-1:2009, Table 7.

Depending on whether or not the short-circuit current is limited by the protective device, the ability to withstand electro-dynamic stresses is illustrated by one of the diagrams shown below:

Case 1 without current limitation:

$I_{\mathrm{p\ max\ BTS}} \geq I_{\mathrm{p\ prospective}} = n \cdot I_{\mathrm{k3}}$

$I_{\mathrm{p\ prospective}} I_{\mathrm{p\ max\ BTS}}$

$\downarrow \downarrow$

$\xrightarrow{\hspace{20em}} I_p$

Case 2with current limitation:

$I_{\text{p max BTS}} \geq I_{\text{p limited}}$

NOTE $I_{\text{p max BTS}}$ (Busbar Trunking System) is given by the manufacturer.

11 Fault protection (protection against indirect contact)

11.1 Disconnecting time

The disconnecting time of the protective device for a earth fault current calculated as indicated in 11.2, shall be less than or equal to the appropriate value given in:

Table 10for TN and TT systems, in accordance with HD 60364-4-41, Table 41.1 and for IT systems in case of a second fault in accordance with HD 60364-4-41, 411.6.4.

Table 10 − Maximum disconnecting time for TN and TT systems and for IT systems in case of a second fault

System	50 V < U_o ≤ 120 V (a.c.) s	120 V < U_o ≤ 230 V (a.c.) s	230 V < U_o ≤ 400 V (a.c.) s	U_o > 400 V (a.c.) s
TN	0,8	0,4	0,2	0,1
TT	0,3	0,2	0,07	0,04
NOTE For IT systems in case of a second fault, the maximum disconnecting time is as for either TN or TT systems, whichever is applicable.				

Table 10 only gives the maximum disconnecting times in the event of a fault of negligible impedance in final circuits not exceeding 32 A.

11.2 Calculation of earth fault current I_{ef}

The minimum earth fault current is calculated for a fault at the downstream end of the circuit. The temperature at which the conductor resistance is determined depends on the characteristics of the protective device and the circuit configuration. The resistivity to be used is selected in accordance with Tables 4 and 5. The minimum earth fault current is required in order to determine if the maximum disconnecting time is fulfilled.

The earth fault current, I_{ef} is equal to:

$$I_{\text{ef}} = \frac{c_{\min} \cdot \alpha \cdot U_0}{\sqrt{\left(R_{\text{SUP}} + R_{\text{U}} + R_{\text{PE}} + R_{\text{ph PE}}\right)^2 + \left(X_{\text{SUP}} + X_{\text{U}} + X_{\text{PE}} + X_{\text{ph PE}}\right)^2}} \qquad (11)$$

where $U_0 = \dfrac{U_{\text{n}}}{\sqrt{3}}$

αcoefficient depending on the earthing system and equal to:

- 1 for TN system;
- 0,86for IT system without neutral conductor;
- 0,50for IT system with neutral conductor.

NOTE 1 This formula can also be used for the calculation of I_{ef} where the supply is a generator. The product c_{min}·1,05(≈1) can be taken as a first approximation in the formula.

a)for insulated conductors and cables:
$$R_{\text{ph PE}} = \left(R_{\text{cx ph}} + R_{\text{cx PE}}\right) \cdot l_{\text{1d}}$$
$$X_{\text{ph PE}} = \left(X_{\text{c ph}} + X_{\text{c PE}}\right) \cdot l_{\text{1d}}$$

or
$$R_{\text{ph PEN}} = \left(R_{\text{cx ph}} + R_{\text{cx PEN}}\right) \cdot l_{\text{1d}}$$
$$X_{\text{ph PEN}} = \left(X_{\text{c ph}} + X_{\text{c PEN}}\right) \cdot l_{\text{1d}}$$

b)for busbar trunking systems:
$$R_{\text{ph PE}} = \left(R_{\text{cx ph}} + R_{\text{cx PE}}\right) \cdot l_{\text{1d}} + R_{\text{bx ph PE}} \cdot l_{\text{2d}}$$
$$X_{\text{ph PE}} = \left(X_{\text{c ph}} + X_{\text{c PE}}\right) \cdot l_{\text{1d}} + X_{\text{b ph PE}} \cdot l_{\text{2d}}$$

or
$$R_{\text{ph PEN}} = \left(R_{\text{cx ph}} + R_{\text{cx PEN}}\right) \cdot l_{\text{1d}} + R_{\text{bx ph PEN}} \cdot l_{\text{2d}}$$
$$X_{\text{ph PEN}} = \left(X_{\text{c ph}} + X_{\text{c PEN}}\right) \cdot l_{\text{1d}} + X_{\text{b ph PEN}} \cdot l_{\text{2d}}$$

Where the lengths l_{1d} and l_{2d} are those related to the downstream circuits (cables and bus bar trunking system respectively).

NOTE 2 ForR_{cx}. , the value of *x* depends on the circuit configuration, the type of the protective device, see Table 4.

For $\begin{matrix} R_{\text{bx phPE}} \\ X_{\text{b phPE}} \end{matrix}$ or $\begin{matrix} R_{\text{bx phPEN}} \\ X_{\text{b phPEN}} \end{matrix}$ see Table 5.

NOTE 3 The following table give the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

	R_{SUP}	X_{SUP}
Transformer		
Delta-Star (Dyn)	$R_Q + R_T + R_C$	$X_Q + X_T + X_C$
Star/Star (Yyn)	$R_Q + R_T + R_C$	$X_Q + 5X_T + X_C$
Delta/Zig-Zag (Dzn)	$R_Q + R_T + R_C$	$X_Q + 0{,}7X_T + X_C$
Generator	R_C	$\frac{2X_d' + X_0}{3} + X_C$
LV Supply	R_Q	X_Q

12 Verification of thermal stress in conductors

12.1Thermal stress

It must be verified that the temperature of the line, neutral and protective conductors does not exceed the maximum permitted temperature given in HD 60364-4-43 and HD 60364-5-54, under short-circuit or fault conditions.

For thermal stress of conductors, it is necessary to verify that the disconnecting time of the protective device does not exceed:

a) for insulated conductors and cables

$$\left(I_{\text{k}}^2 t\right)_{\text{Protective\_device}} < \left(I^2 t\right)_{\text{cable}} = k^2 S^2 \quad (12)$$

For very short durations (< 0,1 s) whether or not asymmetry is present or for current limiting devices, $k^2 S^2$ shall be greater than the value of the let-through energy ($I^2 t$) quoted by the manufacturer of the protective device.

$t$being the disconnecting time for the current I_{k} , [s];

k being a factor the value of which is given in the Table 11, taken from HD 384.5.54;

S being the cross-sectional area of the conductors, [mm²];

I_{k} being: - for live conductors, the minimum short-circuit current $I_{\mathrm{k1\,min}}$ or $I_{\mathrm{k2\,min}}$,

- for protective conductor and PEN conductor, the earth fault current $I_{\mathrm{e_f}}$, [A].

Table 11 − Values of the factor *k*

	Material of conductors	
	Copper	Aluminium
Live conductors and protective conductors forming part of the same wiring system:		
- insulated with Thermoplastic 70 °C (PVC):		
≤ 300 mm²	115	76
> 300 mm²	103	68
- insulated with thermosetting 90 °C (EPR or XLPE)	143	94
- insulated with 85 °C rubber	134	89
Separate protective conductors:		
- insulated with Thermoplastic 70 °C (PVC):		
≤ 300 mm²	143	95
> 300 mm²	133	88
- insulated with thermosetting 90 °C (EPR or XLPE)	176	116
- insulated with 85 °C rubber	166	110
- bare [a]	159	105
[a] where there is no fire risk.		

NOTE 1 High earth fault current may lead to excessive mechanical stress in insulated conductor and cables.

NOTE 2 *k* values for other insulation materials may be derived from IEC 60724.

b) for busbar trunking systems:

$$\left(I_{\mathrm{k}}^{2}t\right)_{\mathrm{Protective\_device}} < I_{0}^{2}t_{0} \quad (13)$$

$I_0^2 \cdot t_0$ being the permissible value of the thermal stress of the conductor (line, neutral, PE or PEN) of the busbar trunking system.

For very short durations (< 0,1 s) whether or not asymmetry is present or for current limiting devices, $k^2\ S^2$ shall be greater than the value of the let-through energy ($I^2\ t$) quoted by the manufacturer of the protective device.

When the protective device is a circuit-breaker, in general it is not necessary to verify the thermal stress in the conductors for the maximum short-circuit current at its place of installation provided that the circuit-breaker is not intentionally delayed.

12.2 Minimum short-circuit current

Verification of thermal stress in live conductors is only necessary if the overload protective device is not placed at the origin of the wiring system (according to HD 60364-4-43:2010, 433.2.2 and 433.3) or if the cross-sectional area of the neutral, PE or PEN conductor is less than that of the line conductors.

In general this requirement to protect the live conductors against thermal stress is covered if the protective device complies with the following condition:

- For circuit breakers complying with EN 60947-2:

$$I_{\mathrm{k}} \geq 1{,}2\ I_{\mathrm{m}}$$

- For circuit breakers complying with EN 60898:

  Curve B: $I_k \geq 5\ I_n$

  Curve C: $I_k \geq 10\ I_n$

  Curve D: $I_k \geq 20\ I_n$

- For fuses complying with EN 60269 series:

  $I_k \geq I_f$

where

I_k being:

- for live conductors, the minimum short-circuit current $I_{k1\ min}$ or $I_{k2\ min}$;
- for protective conductor and PEN conductor, the earth fault current I_{e_f} [A];

I_f being the fusing current resulting in a operating time within 5 s.

NOTE In the case an overload protective device is placed at the origin of the wiring system it would be convenient to verify the operation conditions of the protective device in case of I_k to cover the protection against fire. These conditions are considered covered if the previous conditions for thermal stress under minimum short-circuit current, as applicable, are complied.

12.3 Calculation of the minimum short-circuit current

12.3.1 General

Where the rules require that the minimum short-circuit current ensures the operation of the protective device, it is necessary to calculate such a current (this current is in general the minimum value of the line to neutral short-circuit current (I_{k1})).

12.3.2 Line to line minimum short-circuit current

The minimum value of the line to line short-circuit current, I_{k2} is equal to:

$$I_{k2\min} = \frac{c_{\min} \cdot U_0 \cdot \sqrt{3}}{2 \cdot \sqrt{\left(R_{\mathrm{SUP}} + R_{\mathrm{U}} + R_{\mathrm{x\,ph}}\right)^2 + \left(X_{\mathrm{SUP}} + X_{\mathrm{U}} + X_{\mathrm{ph}}\right)^2}} \qquad (14)$$

where $U_0 = \frac{U_n}{\sqrt{3}}$

NOTE 1The subindex "x" of R_{xph} depends on the applicable resistivity according to Table 4.

NOTE 2The following table give the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

	R_{SUP}	X_{SUP}
HV Supply + Transformer	$R_Q + R_T + R_C$	$X_Q + X_T + X_C$
Generator	R_C	$X_d + X_C$
LV Supply	$R_Q + R_C$	$X_Q + X_C$

a) for insulated conductors and cables:

$$R_{\mathrm{x\,ph}} = R_{\mathrm{cx\,ph}} \cdot l_{1d}$$
$$X_{\mathrm{ph}} = X_{\mathrm{c}} \cdot l_{1d}$$

b) for busbar trunking systems:

$$R_{x\,ph} = R_{cx\,ph} \cdot l_{1d} + 0{,}5 R_{bx\,ph\,ph} \cdot l_{2d}$$
$$X_{ph} = X_c \cdot l_{1d} + 0{,}5 X_{b\,ph\,ph} \cdot l_{2d}$$

where the lengths l_{1d} and l_{2d} are those related to the circuits downstream of the protective device (cables and bus bar trunking system respectively).

12.3.3 Line to neutral minimum short-circuit current

The minimum value of the line to neutral short-circuit current, I_{k1} is equal to:

$$I_{k1\,\mathrm{min}} = \frac{c_{\mathrm{min}} \cdot U_0}{\sqrt{\left(R_{\mathrm{SUP}} + R_{\mathrm{U}} + R_{\mathrm{N}} + R_{\mathrm{x\,ph\,N}}\right)^2 + \left(X_{\mathrm{SUP}} + X_{\mathrm{U}} + X_{\mathrm{N}} + X_{\mathrm{ph\,N}}\right)^2}} \qquad (15)$$

where $U_0 = \frac{U_{\mathrm{n}}}{\sqrt{3}}$

NOTE 1 The subindex "x" of R_{xphN} depends on the applicable resistivity according to Table 4.

a) for insulated conductors and cables:

$$R_{\mathrm{x\,ph\,N}} = \left(R_{\mathrm{cx\,ph}} + R_{\mathrm{cx\,N}}\right) \cdot l_{\mathrm{1d}}$$
$$X_{\mathrm{ph\,N}} = \left(X_{\mathrm{c\,ph}} + X_{\mathrm{c\,N}}\right) \cdot l_{\mathrm{1d}}$$

b) for busbar trunking systems:

$$R_{\mathrm{x\,ph\,N}} = \left(R_{\mathrm{cx\,ph}} + R_{\mathrm{cx\,N}}\right) \cdot l_{\mathrm{1d}} + R_{\mathrm{bx\,phN}} \cdot l_{\mathrm{2d}}$$
$$X_{\mathrm{ph\,N}} = \left(X_{\mathrm{c\,ph}} + X_{\mathrm{c\,N}}\right) \cdot l_{\mathrm{1d}} + X_{\mathrm{b\,phN}} \cdot l_{\mathrm{2d}}$$

where the lengths l_{1d} and l_{2d} are those related to the circuits downstream of the protective device (cables and bus bar trunking system respectively).

NOTE 2 For $R_{\mathrm{cx\,ph}}$ or $R_{cx\,\mathrm{N}}$,the values of x depend on circuit configuration, the type of the protective device, see Table 4.

For $R_{\mathrm{bx\,phph}}$ $X_{\mathrm{b\,phph}}$ or $R_{\mathrm{bx\,phN}}$ $X_{\mathrm{bx\,phN}}$ see Table 5.

NOTE 3 The following table gives the various resistances and reactances that constitute R_{SUP} and X_{SUP} respectively, depending on the type of supply:

	R_{SUP}	X_{SUP}
Transformer		
Delta-Star (dYn)	$R_{\mathrm{Q}} + R_{\mathrm{T}} + R_{\mathrm{C}}$	$X_{\mathrm{Q}} + X_{\mathrm{T}} + X_{\mathrm{C}}$
Star/Star (yYn)	$R_{\mathrm{Q}} + R_{\mathrm{T}} + R_{\mathrm{C}}$	$X_{\mathrm{Q}} + 5X_{\mathrm{T}} + X_{\mathrm{C}}$
Delta/Zig-Zag (dZn)	$R_{\mathrm{Q}} + R_{\mathrm{T}} + R_{\mathrm{C}}$	$X_{\mathrm{Q}} + 0{,}7X_{\mathrm{T}} + X_{\mathrm{C}}$
Generator	R_{C}	$\frac{2X_{\mathrm{d}}' + X_0}{3} + X_{\mathrm{C}}$
LV Supply	R_{Q}	X_{Q}

13 Voltage drop

13.1 The relative voltage drop (expressed as a percentage of the line to neutral voltage) is calculated using the following equation:

$$\Delta u = 100 \cdot \frac{b\left(R_{\mathrm{1\,ph}} \cos\varphi + X_{\mathrm{ph}} \sin\varphi\right) \cdot I_{\mathrm{B}} \cdot 10^{-3}}{U_0} \ \% \qquad (16)$$

- $b$being equal to 1 for three-line circuits;

equal to 2 for line-to-neutral circuits.

- R and X in milliohms,

NOTE Three-line circuits with the neutral completely unbalanced (a single line loaded) are considered a single-line circuits.

where

a)for insulated conductors and cables:- three-line circuits $$R_{1\text{ph}} = R_{\text{c1 ph}} \cdot l_1$$ $$X_{\text{ph}} = X_{\text{c ph}} \cdot l_1$$

- line to neutral circuits $$R_{1\text{ph}} = R_{\text{c1 ph}} \cdot l_1$$ $$X_{\text{ph}} = X_{\text{c ph}} \cdot l_1$$

b)for busbar trunking systems:- three-line circuits $$R_{1\text{ph}} = R_{\text{c1 ph}} \cdot l_1 + R_{\text{b1 ph}} \cdot l_2 \cdot K_{\text{c}}$$ $$X_{\text{ph}} = X_{\text{c ph}} \cdot l_1 + X_{\text{b ph}} \cdot l_2 \cdot K_{\text{c}}$$

- line to neutral circuits $$R_{1\text{ph}} = R_{\text{c1 ph}} \cdot l_1 + 0.5 R_{\text{b1 ph N}} \cdot l_2$$ $$X_{\text{ph}} = X_{\text{c ph}} \cdot l_1 + 0.5 X_{\text{b ph N}} \cdot l_2$$

$\cos\varphi$ being the power factor; in the absence of more precise information, the power factor is taken as *0,8(* $\sin\varphi = 0{,}6$)

K_{c} load distribution coefficient taken as equal to:

1 if the load is concentrated at the end of the wiring system;

$\frac{n+1}{2n}$ if the load is uniformly spread between *n* branches of the wiring system.

The load distribution coefficient value K_{c} is valid for calculating the voltage drop at the end of the wiring system.

To calculate the voltage drop at the origin of a branch situated at the distance *d* from the origin of the busbar trunking system, the coefficient K_{c} is taken as equal to:

$$K_{\text{c}} = \frac{2n + 1 - n \cdot d/l}{2n} \quad (17)$$

in the case of loads spread uniformly along the length of the wiring system.

13.2 The relative voltage drop (expresses as a percentage of the line to neutral voltage) is taken as equal to:

$$\Delta\text{u} = 100 \frac{\text{u}}{U_0}$$

Annex A

Conductor resistances

The tabulated conductor resistances given in this appendix are based on the values given in EN 60228 'conductors of insulated cables'. The resistances have been adjusted to allow for skin and proximity effects calculated in accordance with IEC 60287 'calculation of the continuous current rating of cables (100 % load factor)'. The allowance for skin and proximity effect has been calculated for touching cables having copper or aluminium conductors. Resistances of spaced cables having copper conductors and cross-sectional areas greater than 400 mm² are also given. It should be noted that for conductor cross-sectional areas greater than about 300 mm², the effect of spacing on reactance is more important than its effect on AC resistance.

Table A.1 − Conductor AC resistances at 20 °C, mΩ / m

Nominal conductor size, mm^2	Conductor material		
	Copper		Aluminium
1,5	12,1		-
2,5	7,41		-
4	4,61		7,41
6	3,08		4,61
10	1,83		3,08
16	1,15		1,91
25	0,727		1,2
35	0,524		0,868
50	0,387		0,641
70	0,268		0,443
95	0,194		0,320
120	0,154		0,253
150	0,125		0,207
185	0,100		0,165
240	0,077		0,126
300	0,062		0,101
400	0,049		0,080
	Spaced [a]	Touching	
500	0,039	0,040	0,064
630	0,031	0,033	0,052
800	0,025	0,028	0,042
1000	0,021	0,025	0,033
1200		-	0,028

[a] The values given for spaced cables are for a centre to centre distance of two times the overall diameter.

NOTE Correction factors for both copper and aluminium resistances of conductors for average conductor temperature are given in Table 2.

Bibliography

HD 60269-2	Low-voltage fuses - Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) - Examples of standardized systems of fuses A to J (IEC 60269-2.)
HD 60269-3	Low-voltage fuses - Part 3: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications) - Examples of standardized systems of fuses A to F (IEC 60269-3.)
IEC 60287 series	Electric cables - Calculation of the current rating
HD 60364-4-41	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock
IEC 60364-5-53	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
IEC 60724	Short-circuit temperature limits of electric cables with rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)
IEC 60865 series	Short-circuit currents - Calculation of effects

National Annex NA

(informative)

UK National Practice

NA.1 Introduction

The technical report sets out a uniform approach to the calculations required for the determination of the required cross-sectional area of conductors and the selection of the appropriate protective devices. This annex sets out additional and alternative calculation methods that are used in the UK.

The information given has been drawn from Appendix 4 of BS 7671. IEE Guidance Note 6, ‘Protection against overcurrent’ and other sources.

The methodology and factors given in Appendix 4 of BS 7671 supplement the guidance given in this Technical Report.

NA.2 Cable parameters

NA.2.1 Resistance and reactance

The method of calculating conductor resistance from a nominal material resistivity value is not generally used in the UK for calculating a.c. conductor resistance. Cable resistance and reactance values required for the calculation of circuit impedance can be obtained from the voltage drop values tabulated in Appendix 4 of BS 7671. The values given in BS 7671 are per metre of circuit not per metre of conductor. To obtain values of R and X for use in the equations given in this Technical Report, the single-phase $(\mathrm{mV/A/m})_r$ and $(\mathrm{mV/A/m})_x$ values given in BS 7671 should be divided by 2. This will give the same value as that obtained by dividing the three phase value by $\sqrt{3}$. For conductor sizes of 16 mm² and less, the tabulated single-phase mV/A/m value is divided by 2 to obtain R, and X is taken as zero. This UK method differs from that used by other CENELEC member countries.

The resistance values obtained from BS 7671 are at maximum conductor operating temperature for the particular cable type. To adjust these values to the temperatures required for the various calculations given in this report the following factors should be applied.

Table NA.1 Temperature correction factors from operating temperature

	Thermoplastic 90 °C (PVC)		Thermoplastic 90 °C (PVC)		Thermosetting 90 °C (EPR or XLPE)	
	Factor	Temperature	Factor	Temperature	Factor	Temperature
R_0	0,83	20 °C	0,78	20 °C	0,78	20 °C
R_1	1,00	70 °C	1,00	90 °C	1,00	90 °C
R_2 ≤ 300 mm²	1,15	$\frac{160+70}{2}=115\ °\mathrm{C}$	1,11	$\frac{160+90}{2}=125\ °\mathrm{C}$	1,25	$\frac{250+90}{2}=170\ °\mathrm{C}$
R_2 > 300 mm²	1,12	$\frac{140+70}{2}=105\ °\mathrm{C}$	1,08	$\frac{140+90}{2}=115\ °\mathrm{C}$		

For example, for a line conductor with thermosetting insulation the R_0 and X values are given by:

$$R_{\mathrm{c2ph}}=\frac{1{,}25\times r}{2\times n_{\mathrm{ph}}} \tag{NA.1}$$

$$R_{\mathrm{c0ph}}=\frac{0{,}78\times r}{2\times n_{\mathrm{ph}}} \tag{NA.2}$$

and $$X_{\mathrm{cph}}=\frac{x}{2\times n_{\mathrm{ph}}} \tag{NA.3}$$

where

r = Tabulated single-phase mV/A/m_r value from BS 7671

x = Tabulated single-phase mV/A/m_x value from BS 7671

If resistance values are obtained from other sources at 20 °C then the correction factors given in Table 2 should be used.

Table NA.2 Temperature correction factors from 20 °C

	Thermoplastic 90 °C (PVC)		Thermoplastic 90 °C (PVC)		Thermosetting 90 °C (EPR or XLPE)	
	Factor	Temperature	Factor	Temperature	Factor	Temperature
R_0	1,00	20 °C	1,00	20 °C	1,00	20 °C
R_1	1,20	70 °C	1,28	90 °C	1,28	90° C
R_2 ≤ 300 mm²	1,38	$\frac{160+70}{2}=115\,°\text{C}$	1,42	$\frac{160+90}{2}=125\,°\text{C}$	1,60	$\frac{250+90}{2}=170\,°\text{C}$
R_2 > 300 mm²	1,34	$\frac{140+70}{2}=105\,°\text{C}$	1,38	$\frac{140+90}{2}=115\,°\text{C}$		

The factors for ρ_2 and ρ_3 given in the main body of this technical report are not generally used in the UK. The resistance values used in the UK for the various calculations are shown in clause NA 2.2.

The UK does not use the resistance at the average of the operating temperature and the maximum permitted fault temperature because it is considered that this would produce an overly pessimistic result.

The UK recognizes that the time/current characteristics of fuses and circuit-breakers given in Appendix 3 of BS 7671 and in manufacturer's data are based on the device being at ambient temperature. In service the characteristics will be influenced by the heat generated by the load current. It is considered that this reduces the disconnection time to such an extent that it negates the reduction in fault current, and hence increase in disconnection time, due to the increases in conductor resistance arising from the heating effect of fault currents. Where the load current is lower than the current carrying capacity of the cable the preheating of the protective device will be less, however the initial temperature at the start of the fault will also be lower and it is considered that the reduction in preheating and lower start temperature compensate for each other.

For circuit-breakers operating on the instantaneous part of the time/current characteristics, the resistance R_1 is used.

Table NA.3 Selection of conductor resistance for cables

RULES	CURRENTS	CIRCUITS	Resistance				
			UPSTREAM CIRCUITS	CIRCUIT			
				Distribution circuit		Final circuit	
MAXIMUM SHORT-CIRCUIT CURRENT	$I_{k3\ max}$	3 Line	R_0	R_0		R_0	
	$I_{k2\ max}$	Line to line	R_0	R_0		R_0	
	$I_{k1\ max}$	Line to neutral	R_0	R_0		R_0	
	PROTECTIVE DEVICE			**Fuse**	**Circuit-breaker**	**Fuse**	**Circuit-breaker**
MINIMUM SHORT - CIRCUIT CURRENT	$I_{k2\ min}$	Line to line	R_1	R_1	R_1	R_1	R_1
	$I_{k1\ min}$	Line to neutral	R_1	R_1	R_1	R_1	R_1
EARTH FAULT CURRENT	I_f	Line to PEN/Line to PE	R_1	R_1	R_1[a]	R_1	R_1
		Line to reduced PEN/Line to reduced P	R_1	R_1	R_1[a]	R_1	R_1
		Line to separate PE					
		For line	R_1	R_1	R_1	R_1	R_1
		For PE [b]	R_1	R_1	R_1	R_1	R_1
		For reduced PE	R_1	R_1	R_1	R_1	R_1
VOLTAGE DROP	I_B	All live conductors [c]	R_1	R_1	R_1	R_1	R_1
Notes:							
[a] Use R_2 if a time delayed circuit-breaker is used							
[b] For conduit, trunking or cable armour used as PE the temperature at which the resistance is calculated is covered in Clauses NA 4.2 to NA 4.4.							
[c] Correction factors for operating temperature may be applied							

NA.2.2 Flexible Conductors

The current-carrying capacities and voltage drops tabulated in BS 7671 are based on cables having solid conductors (Class 1) or stranded conductors (Class 2) except for Tables 4F1A to 4F3B of BS 7671 Appendix 4. To obtain the correct current-carrying capacity or voltage drop for cables types similar to those covered by other tables but with flexible conductors (Class 5), the tabulated values are multiplied by the following factors:

Table NA.4 Flexible Conductors

Cable size	Current-carrying capacity	Voltage drop
≤ 16 mm²	0,95	1,10
≥ 25 mm²	0,97	1,06

NA.2.3 Current-carrying capacity factors

To determine the current-carrying capacity of a cable for continuous service under the particular installation conditions concerned, I_z, the tabulated current-carrying capacity, I_t, is multiplied by the relevant rating factors. Rating factors for ambient temperature, circuits buried in the ground, depth of burial, grouping, thermal insulation and thermal resistivity of the soil are given in BS 7671.

NA.3 Coordination between conductors and overload protective devices

The formulae given in the main body of this Technical Report for coordination between conductors and overload protective devices are valid for single circuits or groups of circuits that may be subjected to simultaneous overload.

Appendix 4 of BS 7671 sets out the formula to be used for groups of circuits that may not be subjected to simultaneous overload.

BS 7671 also includes a factor to be applied when the overload protective device is a semi-enclosed fuse.

NA.4 Earth fault

NA.4.1 Loop impedance

BS 7671 provides tabulated values of maximum earth fault loop impedance, in Chapter 41, for a range of protective devices. The values given are based on the conductors being at their maximum operating temperature.

NA.4.2 Cables in steel conduit

Where steel conduit is used as a protective conductor the effective resistance and reactance of the line-protective conductor loop is given by the following equations.

$$R_{\mathrm{phPE}} = \left(R_{\mathrm{c1ph}} + F_{\mathrm{r}} R_{\mathrm{dc}}\right) l_1 \tag{NA.4}$$

$$X_{\mathrm{phPE}} = F_{\mathrm{x}} R_{\mathrm{dc}} l_1 \tag{NA.5}$$

where

R_{dc} = d.c. resistance of conduit at working temperature (Assumed as 50 °C, conduit resistance at 20 °C is multiplied by 1,14)

F_{r} = factor to take account of the magnetic effect of the steel, Table NA.5

F_{x} = factor to take account of the reactive effect of the steel, Table NA.5

Table NA.5 Values of F_r and F_x for steel conduit

Heavy gauge conduit				
Size of conduit	Fault current			
	Up to 100 A		Above 100 A	
mm	F_r	F_x	F_r	F_x
16	3,0	2,0	1,3	1,3
20	2,8	1,9	1,3	1,3
25	2,4	1,7	1,1	1,1
32	2,0	1,4	0,92	0,92
Light gauge conduit				
16	2,3	1,6	1,3	1,3
20	2,1	1,4	1,3	1,3
25	1,9	1,3	1,1	1,1
32	1,8	1,3	1,1	1,1

NA.4.3 Cables in steel trunking

Where steel trunking is used as a protective conductor the effective resistance and reactance of the line-protective conductor loop is given by the following equations for circuits carrying no more than 100 A. Steel trunking is not generally considered suitable for use as a protective conductor for circuits carrying much more than 100 A.

$$R_{\mathrm{phPE}} = \left(R_{\mathrm{c1ph}} + 2{,}1R_{\mathrm{dc}}\right)l_1 \qquad \text{(NA.6)}$$

$$X_{\mathrm{phPE}} = 2R_{\mathrm{dc}}l_1 \qquad \text{(NA.7)}$$

where

R_{dc} = d.c. resistance of trunking at working temperature (assumed as 50 °C, conduit resistance at 20 °C is multiplied by 1,14)

2,1 = coefficient to take account of the magnetic effect of the steel

2 = coefficient to take account of the reactive effect of the steel

NA.4.4 Steel wire armoured multicore cables

Where steel wire armour of a multicore cable is used as a protective conductor the effective resistance and reactance of the line-protective conductor loop is given by the following equations.

$$R_{\mathrm{phPE}} = \left(R_{\mathrm{c1ph}} + 1{,}1R_{\mathrm{a}}\right)l_1 \qquad \text{(NA.8)}$$

$$X_{\mathrm{phPE}} = 0{,}3l_1 \qquad \text{(NA.9)}$$

where

R_{a} = d.c. resistance of armour at working temperature (armour resistance at 20 °C is multiplied by 1,18 for cables having 70 °C thermoplastic insulation and 1,27 for cables having 90 °C thermosetting insulation)

The factor 1,1 is a multiplier to take account of the magnetic effect of the steel armour.

NA.4.5 External cpc in parallel with steel wire armour

Where an external cpc is run in parallel with the steel wire armour of a multicore cable the effective resistance and reactance of the line-protective conductor loop is given by the following equations. The external cpc is taken to be in contact with the sheath of the steel wire armoured cable.

$$R_{\mathrm{phPE}} = \left(R_{\mathrm{c1ph}} + R_{\mathrm{p}}\right) l_1 \qquad \text{(NA.10)}$$

$$X_{\mathrm{phPE}} = 0{,}4 l_1 \qquad \text{(NA.11)}$$

where

$$R_{\mathrm{p}} = \frac{1}{\dfrac{1}{1{,}1R_{\mathrm{a}}} + \dfrac{1}{R_{\mathrm{cpc}}}}$$

R_{a} = d.c. resistance of armour at working temperature (armour resistance at 20 °C is multiplied by 1,18 for cables having 70 °C thermoplastic insulation and 1,27 for cables having 90°C thermosetting insulation)

R_{cpc} = d.c. resistance of cpc at working temperature of the cable sheath (Although the sheath temperature will be 10 °C to 15 °C lower than the line conductor temperature it is convenient to assume that the cpc is at the same temperature as the line conductors.)

R_{p} = resistance of armour and cpc in parallel taking account of the magnetic effect in the steel armour

It is also necessary to confirm that the fault current withstand capacity of the external cpc is not exceeded. This can be achieved by selecting an external cpc that has a cross-sectional area that is not less than a quarter of that of the line conductor. Alternatively the proportion of the fault current carried by the cpc can be calculated and compared with the fault current withstand capacity of the cpc.

The current carried by external cpc is:

$$I_{\mathrm{cpc}} = I_{\mathrm{ef}} \frac{1{,}1R_{\mathrm{a}}}{1{,}1R_{\mathrm{a}} + R_{\mathrm{a}}} \qquad \text{(NA.12)}$$

The current carried by the armour is:

$$I_{\mathrm{a}} = I_{\mathrm{ef}} \frac{\sqrt{R_{\mathrm{cpc}}^2 + 0{,}2^2}}{\sqrt{\left(1{,}1R_{\mathrm{a}} + R_{\mathrm{cpc}}\right)^2 + 0{,}2^2}} \qquad \text{(NA.13)}$$

where

I_{a} = fault current carried by the armour

I_{cpc} = fault current carried by the external cpc

NA.4.6 Aluminium wire armoured single-core cables

The following equations apply to a three-phase circuit of one cable per phase with the earth fault at the load end of the run and solid bonded armour.

$$R_{\mathrm{phPE}} = \left(R_{\mathrm{c1ph}} + C_{\mathrm{r}} R_{\mathrm{a}}\right) l_1 \tag{NA.14}$$

$$X_{\mathrm{phPE}} = \left(X_{\mathrm{ca}} + C_{\mathrm{x}} R_{\mathrm{a}}\right) l_1 \tag{NA.15}$$

where

R_{a} = d.c. resistance of armour at working temperature (armour resistance at 20 °C is multiplied by 1,18 for cables having 70 °C thermoplastic insulation and 1,27 for cables having 90 °C thermosetting insulation)

C_{r} = coefficient to take account of the armour of three cables in parallel with unequal current sharing between the armours, Table NA.6

C_{x} = coefficient obtain the effective reactance of the three armours in parallel, Table NA.6

X_{ca} = reactance of conductor armour loop = $0{,}0628 \ln\left(\dfrac{d_{\mathrm{a}}}{ad}\right)$ (in the absence of more precise information X_{ca} may be taken as 0,035 mΩ/m)

d_{a} = mean diameter of armour

a = stranding coefficient, Table NA.7

d = conductor diameter

Table NA.6 Values of C_{r} and C_{x} for single-core aluminium wire armoured cable to BS 5467 or BS 6724

Nominal conductor cross-sectional area, mm²	Trefoil		Flat formation			
			Touching		Spaced	
	C_{r}	C_{x}	C_{r}	C_{x}	C_{r}	C_{x}
150	0,35	0,09	0,35	0,14	0,38	0,20
185	0,35	0,10	0,35	0,15	0,39	0,21
240	0,35	0,11	0,36	0,16	0,40	0,23
300	0,35	0,12	0,36	0,17	0,41	0,25
400	0,37	0,16	0,39	0,24	0,47	0,31
500	0,38	0,17	0,39	0,25	0,49	0,33
630	0,39	0,18	0,40	0,26	0,51	0,33
800	0,43	0,23	0,45	0,33	0,60	0,37
1000	0,44	0,24	0,47	0,34	0,63	0,37

For sizes up to and including 120 mm² C_{r} = 0,33 and C_{x} = 0

Table NA.7 Stranding coefficients

Number of strands in conductor	Coefficient, a
1	0,779
3	0,678
7	0,724
19	0,758
37	0,768
61	0,772
91	0,774
127	0,776

NA.5 Protective device characteristics

NA.5.1 Circuit-breakers

In addition to the two characteristics that are considered in Clause 7.1 it may be necessary to verify the thermal stress in the conductors for the maximum fault current at the position of the circuit-breaker.

NA.5.2 Fuses

Appendix 3 of BS 7671 provides time/current characteristics for fuses to BS 88-2 fuse systems E and G, BS 88-3 fuse system C and BS 3036 semi-enclosed fuses. Either these curves or manufacturer's data should be used in preference to the equation given in Clause 7.2.

NA.6 Verification of thermal stress in conductors

Clause 12 of the main body of this Technical Report sets out details for calculation of thermal stress in conductors. The final paragraph of Clause 12.1 indicates that, in general, when the protective device is a circuit breaker it is not necessary to verify the thermal stress in the conductors for the maximum short-circuit current at its place of installation. However in the UK it is considered that it may be necessary to verify the thermal stress in the conductors for this position.

NA.7 Voltage drop

BS 7671 Appendix 4 contains tabulated values of voltage drop for a range of cable types. It is recommended that these values are used in preference to the resistivity and single reactance values given in the body of this report.

Values given in BS 7671 for single-phase circuits are line to neutral values and the values given for three-phase circuits are line to line values. For conductor sizes above 16 mm² the values given include the resistive, r, and reactive, x, components.

Voltage drop, v_d, with correction for load power factor is given by:

$$v_\mathrm{d} = \left[\cos\phi\left(\mathrm{mV/a/m}\right)_r + \sin\phi\left(\mathrm{mV/a/m}\right)_x\right] I_\mathrm{dB} l_1 10^{-3} \qquad \text{(NA.16)}$$

The tabulated r values are given at maximum conductor operating temperature. Where the design load is less than the current-carrying capacity of the cable under the particular installation conditions the resistive component of the voltage drop may be corrected for temperature using the correction factor C_t.

$$C_\mathrm{t} = \frac{230 + t_\mathrm{p} - \left(C_\mathrm{a}^2 C_\mathrm{g}^2 C_\mathrm{s}^2 C_\mathrm{d}^2 - \dfrac{I_\mathrm{B}^2}{I_\mathrm{t}^2}\right)\left(t_\mathrm{p} - 30\right)}{230 + t_\mathrm{p}} \qquad \text{(NA.17)}$$

where

t_p = maximum permitted normal operating temperature, °C

C_a, C_g, C_s, C_d = rating factors

NA.8 Ring circuits

NA.8.1 General

Ring circuits protected by 30 A or 32 A devices are traditionally used to supply permanently connected equipment and a number of socket outlets. Because the distribution of the load around the ring is not usually known a number of assumptions usually have to be made to carry out the required calculations.

NA.8.2 Ring circuit cable rating

The minimum permitted current carrying capacity, I_Z, of the cable used for a 30 A or 32 A ring circuit is 20 A. Thus the required current carrying capacity of the cable selected is calculated from the following formula:

$$I_{\mathrm{t}} \geq \frac{20}{C_{\mathrm{a}} C_{\mathrm{f}} C_{\mathrm{g}} C_{\mathrm{i}}} \qquad \text{(NA.18)}$$

NA.8.3 Voltage drop

The simplest assumption that can be made to calculate the maximum voltage drop in a ring circuit is to assume that the full design load is carried by equipment connected to the farthest point in the ring circuit. In this case the load is equally shared by both legs of the ring and the length of each leg is equal to half the length of the ring circuit. In this case the maximum voltage drop is given by:

$$v_d = \frac{I_B}{2} \frac{l_1}{2} \frac{(\mathrm{mV/a/m})}{1000} \qquad \text{(NA.19)}$$

Note: For the worst case situation I_{B} is the design current for the ring circuit, 32 A. However, in a ring circuit the full design current is unlikely to be drawn from a single point. An alternative is to assume that 20 A is drawn at the far end and the remaining 12 A is evenly distributed around the ring. In this case the current to be used in place of I_{B} is (32+20)/2 = 26 A.

NA.8.4 Fault protection

For earth fault current calculations it is assumed that the fault occurs at the furthest point from the origin of the ring circuit. With the fault at this position the fault current is equally divided between the two legs of the ring and the length of each leg is equal to half the length of the ring circuit. The contribution of the ring circuit to the fault loop impedance is given by:

$$\left(R_{\mathrm{c1ph}} + R_{\mathrm{c1PE}}\right)\frac{l_1}{4} \qquad \text{(NA.20)}$$

The cable sizes used for 30 A and 32 A ring circuits are such that only the resistive component of the ring circuit cables needs to be considered with their inductance being neglected.

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